BUS TRANSIT PLANNING FOR A LARGE CITY AND DECISION SUPPORT SYSTEM OF FEEDER BUS ROUTES FOR RAIL TRANSIT NETWORK

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of

DOCTOR OF PHILOSOPHY

by

RAMAN PARTI

to the

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

September, 2002

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CERTIFICATE

It is certified that the work contained in the thesis "BUS TRANSIT PLANNING FOR A LARGE CITY AND DECISION SUPPORT SYSTEM OF FEEDER BUS ROUTES FOR RAIL TRANSIT NETWORK", by Raman Parti, has been carried out under our supervision and that this work has not been submitted elsewhere for a degree.

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To

My Father and Mother,

With

Profound Respect

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Raman Parti

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LIST OF SYMBOLS AND ABBREVIATIONS

AT_{factor}	Attraction factor
$a_0,a_1,a_2,\ldots,a_n$	Parameters for utility function of bus transit system
$b_0,b_1,b_2,\ldots,b_n$	Parameters for utility function of MRTS
C	Cluster centers
CAP	Capacity of buses operating on the network
C_fort_{Bus}	Comfort level of Bus transit network
C_fort_{MRTS}	Comfort level of MRTS
CBD	Central Business District
Con_mrts(i,j)	Connectivity matrix between stops and first MRTS station
C.R	Central Railways
C1	Cost of one passenger-hour of travel time
C2	Cost of one bus (including capital and operating cost over time Period)
d	Euclidean distance
dem_{ij}	Demand between i and j
dem_j	Demand at station i
$Demand(s_p)$	Share of demand from stop to generated path
DSS	Decision Support System
ESRI	Environmental System Research Institute
Est_T	Estimated bus trips
f_r	Frequency of buses plying on route r
FCM	Fuzzy-C-Means
GA	Genetic Algorithm
GIS	Geographical Information System
h	Neighborhood function
hb	Hub

HFRGA	Heuristic feeder route generation algorithm
I.A.	Influence Area
i,j	Origin and Destination node pair
Int_stop_dem(i,j)	Inter stop demand between O-D pair
Int_zon_dem(zt_1,zt_2)	Inter zonal demand between two zones
Int_Nod_MRTS(i,j)	Inter nodal demand between O-D pair through MRTS
Inf_{hb}	Influence area of hub
IPT	Intermediate public transport
IWT	Initial waiting time
KBES	Knowledge based expert system
L	Link
LL_r	Length of route r
LL_{min}	Minimum length constraint of route
LL_{max}	Maximum length constraint of route
LOS	Level of service
m	Weighing component
mt, nt	MRTS Stations
MDVS	Multiple depot vehicle scheduling
MRTS	Mass Rapid Transit System
N	Total number of stops/nodes
NB	Total number of bus stops
NBB	Number of buses to operate the system
NP_r	Number of buses plying on route r
O-D	Origin and Destination
P_{Bus}	Proportion of demand of bus transit system
P_{MRTS}	Proportion of demand for MRTS
PD_{factor}	Production Factor
P_L_F	Passenger Link Flow
$(q_{ij})^r_{max}$	Maximum flow occurring on any link of route r
r	Route
R_T_T	Round trip time

RUC	Route Utilization Coefficient
SA	Simulated Annealing
SCP	Set Covering Problem
Sec_mrts(i,j)	Connectivity matrix between stops and second MRTS station
SOM	Self Organizing Map
SPLP	Simple plant location problem
Sh_MRTS dis(mt,nt)	Shortest inter MRTS station distance matrix
Sh_MRTS T_T(mt,nt)	Shortest inter MRTS station travel time matrix
Sh_road dis(i,j)	Shortest inter-stop distance matrix
Sh_road T_T(i,j)	Shortest inter-stop travel time matrix
Sh_Stop MRTS dis(i,mt)	Shortest distance matrix from stops to MRTS stations
Sh_Stop MRTS T_T(i,mt)	Shortest travel time matrix from stops to MRTS stations
Share_MRTS(i,j)	Proportionate share matrix of inter-nodal demand through MRTS
SR	Set of transit routes
ST	Terminal stop
SQL	Structured query language
T	Transfer Point
T_cost_{Bus}	Travel cost of bus transit network
T_cost_{MRTS}	Travel cost of MRTS
T_T or t_t	Total travel time
T_Time_{Bus}	Travel time of bus transit network
T_Time_{MRTS}	Travel time of MRTS
$Trans\_plt_{Bus}$	Transfer penalty of bus transit network
$Trans\_plt_{MRTS}$	Transfer penalty of MRTS
T_T_k	Total travel time through node k
T_Time(s,k)	Shortest travel time through nodes 's' and 'k'
TT_Road	Travel time through road
TT_MRTS	Travel time through MRTS
TRUST	Transit routes analyst
TSM	Transportation System Management
$t_{tt,ij}$	Travel time between i and j

$t_{wt,k}$	Waiting time at stop k
$t_{inv,ij}$	In vehicle time between i and j
$t_{tr,ij}$	Transfer time incurred between node pair i and j
UC_{Bus}	Utility Measure of bus transit network
UC_{MRTS}	Utility Measure of MRTS
U	Fuzzy partition matrix
V	Vector of cluster centers
VRPs	Vehicle routing problems
W	Fleet size available for operation
W_A_L_F	Weighted average link flow
WP	Production weight at stop
WA	Attraction weight at stop
W.R	Western railways
X	Input pattern
Z	Set of bus stops
ZT	Traffic zone
μ	Membership function
λ	Langrange's multiplier
ε	Tolerance limit
ξ	Total number of neurons in a network
ω_0	Current count of iterations
ω	Total count of iterations
σ	Effective width of topological neighborhood
η	Learning rates

CHAPTER – 1

INTRODUCTION

1.1 GENERAL

Our increasingly Urbanized civilization must pay attention to its cities, which are growing in size and complexity. One of the major challenges of our time is how to ensure that cities have operationally and economically efficient services, which enhance their environmental, social and cultural values. Cities have always been the centers of human activities. In addition to being seats of governance, they have been central locations of manufacturing, trade, educational, cultural, and other activities. However, before the development of large-scale industrial processes, most people resided in rural areas and were employed in agricultural sector of the economy. This pattern was completely changed by the industrial revolution, which was initiated and sustained by many institutional, economic, and technological developments in the course of eighteen and nineteen centuries. New jobs in cities offered employment opportunities and attracted the rural population with the prospects of higher wages. The major shift proceeded from the primary sector of economy (agricultural) to secondary (manufacturing industry) and tertiary (government, administration, banking, trade, education, culture) sectors. Because the secondary and tertiary sectors are concentrated primarily in towns and cities, the employment shift among the various sectors were accompanied by a massive movement of population from rural to urban areas, the process called 'Urbanization'. The process of urbanization further compounded by the population increase and resulted in chaotic conditions in the urban areas.

1.2 URBAN TRANSPORT

1.2.1 Challenges of Urban Transport

The founding, shaping, and growth of human agglomerations throughout history have been products of complex interactions of many forces. The transportation is one of those major forces. A review of historic developments will show how long-distance transportation had a major role in determining the locations of cities; how their size has been influenced by both long-distance as well as local, intra-urban transportation; and how the latter has affected the urban form (shape of urban area and its basic transportation network) and urban structure (distribution of land uses and population densities).

Tremendous progress in transportation technology has been achieved during the last century. The great impact that the transportation developments have had on modern civilization is also evident i.e. the intensive urbanization that has taken place in all countries would not have been possible without modern transportation systems. In light of this abundance of technologies, it appears paradoxical that today many cities suffer from serious transportation problems. The problems include poor quality of service (low speed, reliability, comfort, safety, etc.), lack of adequate transportation for some population groups, financial problems, and, often the most serious one, strong negative impacts of urban transportation systems on cities and their environments.

These problems are mostly consequences of various deficiencies in planning, financing, and organization of urban transportation, rather than technological failures. Although the historical developments clearly show that there is a strong interdependence between quality and type of transportation service on one side, and urban form, size, and character on the other, city governments have often failed to understand the role of transportation. A particular important problem has been to allocate proper roles to different transport modes. Because of this inadequate understanding, often-weak public leadership, and low ability to implement plans, public transport in many cities has been seriously neglected. Regulation of auto travel has been so inadequate that the great potential mobility of this

mode is often defeated by congestion, while pedestrians have little pleasure, or even safety, while walking in many urban areas.

Urban transport is an important component of the urban infrastructure system. A good urban transport system will increase productivity, enhance efficiency, ensure competition, and promote urban economy. It will also facilitate social interactions, provide people with accessibility to opportunities, safeguard environment, set directions and pattern of land use development, and ensure quality of life. The impacts of a poor urban transport are manifested in terms of congestion, delays, pollution, accidents, high-energy consumption, low productivity of resources, community severance, and inadequate access to services.

1.2.2 Urban Public Transport

Urban public transportation, commonly known as 'transit', has been properly refereed to as the 'lifeblood of cities'. Neglected in some countries during the period of rapid growth in auto ownership, its role has now been recognized as essential for achieving physically attractive, economically sound, and energy efficient cities. Majority of the large cities in developing countries suffer seriously from poor mobility, pollution, noise, accidents, and economic waste caused by chronic traffic congestion. This condition is often a consequence of the failure to ensure an acceptable level of transit service through separation of this mode from other traffic. It also results from the lack of a comprehensive transportation policy that would either provide adequate facilities, or control demand through regulatory and pricing measures, rather than allow chronic congestion.

Observing generally the urban transportation trends in different countries, it can be easily seen that the growth of cities increases the total volume of travel. The massive growth in population coupled with stepping up of commercial, economic and administrative activities and also the expansion of geographical area, leads to conversion of walk trips into vehicular trips. The trip rates and the trip lengths increase and the final result is a heavy volume of traffic. As the city size grows, vehicular trips get concentrated on particular sections and the routes and the travel mode changes from cycles, two wheelers

and intermediate public transport modes to a bigger unit like a bus. With a further increase in city size and traffic volume, the need arises for a high capacity mode like an intra-urban rail service. How much of that increase goes to transit modes depends on auto-ownership level, transit L/S, and policies toward the two systems.

When rapid increase in auto ownership occurs (which takes place in different countries at different times), major efforts are focused on construction and modernization of highway/street system, parking, and related facilities. Transit systems are usually negatively affected by these developments. Their modernization is given much less attention than highway construction. In many cases transit is totally neglected, or its rights-of-way are taken over for street widening – a very costly mistake in the long run.

1.2.3 Mass Rapid Transit System

As cities grow in size, the number of vehicular trips on road system goes up. This necessitates a pragmatic policy shift to discourage private modes and encourage public transport. Once the level of traffic along any travel corridor in one direction exceeds 20,000 persons per hour, introduction of a rail based mass rapid transit system is called for. Mass rapid transit systems are capital intensive and have long gestation period. It has been observed that in developed countries, planning for mass transit system starts when city population exceeds 1 million. The system is in position by the time the city population is 2 to 3 million and once the population exceeds 4 million or so, planned extensions to the Mass Rapid Transit (MRT) Systems is vigorously taken up. In developing countries including India, because of paucity of funds planning and implementation of rail based mass rapid transit systems has been lagging far behind the requirements.

1.2.4 System Integration of Public Transportation System

The efficiency of different modes of transport and main transit facility can be enhanced by system integration. System integration occurs at three levels: Institutional, Operational and Physical.

Institutional integration refers to the creation of an organizational framework within which joint planning and operation of transit services can be carried out. Four types of organizational arrangements named Tariff association, Transit communities, Transit federation and Mergers are considered for implementing transit integration.

Operational integration involves the application of management techniques to optimize the allocation of transit resources and co-ordinate services. The techniques of operational integration include rationalization of redundant services, matching modes to service requirements, unification of fare structure, fare discounts, co-ordinated public information systems, reserved bus lanes and streets, development of feeder routes, development of co-ordinated schedules, parking controls etc. Development of feeder routes and schedule co-ordination for feeder services is the most important aspect of operational integration.

Physical integration refers to the provision of jointly used facilities and equipment. Techniques of physical transit integration include inter-modal terminals, transit shelters, park-and-ride facilities, and pedestrian facilities.

1.3 URBAN PUBLIC TRANSPORT IN INDIA

The extent to which Indian cities meet the challenges of urbanization and contribute to macroeconomic performance and poverty reduction will depend, to a large extent, on how efficiently their transport systems move people, goods, and services upon which their economic activities depend.

India's urban population, according to the 2001 census, stood at 285 million, which is 27.8 per cent of the country's total population of 1027 million. Growth since independence is shown in Table 1.1. Comparing the level of urban population in India with that of the few selected countries in the world given in Table 1.2 shows that the growth of urbanization as such, in India has been only modest. While the rate of urbanization in India has been quite moderate, the increase in urban population, in

absolute terms, from 62 million in 1951 to 217 million in 1981 and further to 285 million in 2001, has been phenomenal.

Table 1.1: India's Rural/Urban Population Growth

Year	Population (in Million)			Urban Population Share (percent)
	Total	Rural	Urban	
1951	361.09	298.64	62.44	17.3
1961	439.23	360.29	78.94	18.0
1971	548.16	438.14	109.11	19.9
1981	683.32	523.87	159.46	23.3
1991	846.39	628.84	217.55	25.7
2001	1027.02	741.66	285.35	27.8

Source: e-CensusIndia, No. 3, Oct. 30, 2001.

Table 1.2: Share of Urban Population in Selected Countries (Percent of Total)

Country	Year	
	1980	1999
Argentina	83	90
Australia	86	85
Belgium	95	97
Brazil	66	81
Canada	76	77
Chile	81	85
China	20	32
Egypt	44	45
Germany	83	87
India	23	28
Indonesia	22	40
Iran	50	61
Japan	76	79
Malaysia	42	57
Pakistan	28	36
Spain	73	77
Sweden	83	83
U.K.	89	89
U.S.A.	74	77
Zambia	40	40

Source: World Development Report 2000/2001, World Bank, Washington, D.C.

An unwelcome feature of the pattern of urbanization in India has been the concentration of population in the metropolitan cities having a population of one million and above. The number of cities (Urban agglomerations) with a million plus population, increased to 35 in the year 2001 (as shown in Table 1.3). These 35 cities taken together contained about 107.9 million people accounting for 37.8 percent of the country's urban population and 10.5 percent of the total population.

Over the last few decades, there has been a phenomenal growth in the number of motor vehicles in the metropolitan cities in India. Data given in Table 1.4 is self-explanatory. The increased use of private auto leads to chronic congestion on the roads. It has been eventually recognized over the worldwide that even with expanded highways and streets, the fact remains that the auto alone cannot satisfy the transportation needs of cities for physical, social, economic, and environmental reasons.

The only solution to congestion relief and provision of service with adequate capacity and quality is through creation of separate, independent transit rights-of-way. Although partial and temporary separations can be achieved through provision of various types of bus lanes, the most effective permanent solution is to construct light rail transit (LRT) and rapid rail transit (RRT) systems.

In India, only three cities, namely, Kolkata, Mumbai and Chennai have intra-urban rail facility. Delhi has a nominal service but an MRTS project is in hand. Other metropolitan cities including those having a population of around 5 million do not have a high capacity rail system to serve urban commuters. What is most disturbing, however is that several metropolitan cities with a population of 2 to 3 million, do not have even a properly organized public bus transport system. Kanpur, Jaipur and Lucknow are glaring examples in this category.

Table 1.3: Urban Agglomerations/Cities having Population of more than one million in 2001

Rank in 2001	Urban Agglomeration/City	Civic Status	Population in 2001 (in Million)
1.	Greater Mumbai	UA	16.37
2	Kolkata	UA	13.22
3	Delhi	UA	12.79
4	Chennai	UA	6.42
5	Banglore	UA	5.69
6	Hyderabad	UA	5.53
7	Ahemdabad	UA	4.52
8	Pune	UA	3.75
9	Surat	UA	2.81
10	Kanpur	UA	2.69
11	Jaipur	M.Corp.	2.32
12	Lucknow	UA	2.27
13	Nagpur	UA	2.12
14	Patna	UA	1.71
15	Indore	UA	1.64
16	Vadodara	UA	1.49
17	Bhopal	UA	1.45
18	Coimbatore	UA	1.45
19	Ludhiana	M.Corp.	1.39
20	Kochi	UA	1.35
21	Visakhapatnam	UA	1.33
22	Agra	UA	1.32
23	Varanasi	UA	1.21
24	Madhurai	UA	1.19
25	Meerut	UA	1.17
26	Nashik	UA	1.15
27	Jabalpur	UA	1.12
28	Jamshedpur	UA	1.10
29	Asansol	UA	1.09
30	Dhanbad	UA	1.06
31	Faridabad	M.Corp.	1.05
32	Allahabad	UA	1.05
33	Amritsar	UA	1.01
34	Vijayabad	UA	1.01
35	Rajkot	UA	1.00
Total			107.88

Source: Rural-Urban distribution of population, Census of India, 2001

Table 1.4: Registered Motor Vehicles in Selected Metropolitan Cities in India (Number in Thousands)

City	Year			
	1992	1995	1997	1998
Mumbai	647	667	797	860
Kolkata	497	561	588	664
Delhi	1963	2432	2848	3033
Chennai	604	768	890	975
Banglore	605	798	972	1130
Hyderabad	485	557	769	887
Ahemdabad	419	510	631	686
Pune	296	358	468	527
Surat	223	301	362	399
Kanpur	186	223	247	282

Source: "Motor Transport Statistics of India – 1997-98", Ministry of Road Transport and Highways, GOI.

1.3.1 Rail Transportation in Typical Metropolitan Cities of India

Urban transportation in Bombay is based on suburban train services, the bus services, taxis, three wheelers, auto rickshaws and personalized vehicles. Public transport in Bombay accounts for more than 80 percent of journeys or trips, with the rail system and buses having almost equal share. However, in terms of passenger kilometers, the railways carry nearly 4 times the traffic carried by buses because of the longer average lead. Bombay Suburban Train Service (BSTS) serves Bombay Metropolitan region from Chhatrapati Shivaji Terminus (CST) extending up to Karjat (100 km) and Kasara (120 km) on Central railway, and from Churchgate up to Virar (60 km) on Western railway. The Central railway suburban network consists of 3 double line corridors starting from CST (Bombay V.T) with one corridor known as slow corridor, another as the fast corridor and the third one is known as Harbour branch. On the slow corridor from V.T to Kalyan, only suburban trains run. On the fast corridor long distance passengers and goods trains run and during the peak hour's fast suburban trains are run as well. On the Harbour branch extending up to Panvel, slow suburban trains and goods trains from Bombay Port Trust are operating.

Similar to Bombay, Chennai in India is also having a suburban railway network. With the sprawl and growth of Chennai, the three important and suburban sections catering to the needs of commuters in the Madras metropolitan area are:

- Madras Beach – Chengalpattu Meter Gauge Section
- Madras Central – Trivellore Broad Gauge Section
- Madras Central – Gummidipundi Broad Gauge Section

Madras Beach – Tambaram that lies on Madras Beach – Chengalpattu meter gauge section is a major corridor with 18 stations and passes through the heart of the Madras city. During morning and evening peak periods the traffic becomes very high on this corridor. The two services viz. suburban trains and public buses are highly in demand. These two facilities can be coordinated effectively for their optimal utilization. Presently, no co-ordination exists between these two public transport modes.

The railway network within Calcutta Metropolitan Authorities (CMA) comprises of 12 railway alignments providing suburban and long distance services. The mass transportation system of the metropolis comprises of suburban rail including circular railway, metro rail, tramways, bus & minibus services and ferry services. DumDum railway junction station in north Calcutta has the unique importance of having three systems of railway for local passengers viz. Metro, Suburban and Circular railway. It is the junction of three sections of sub-urban railway viz. Ranaghat, Bangaon and Dankuni section. The metro railway connects DumDum to Tollygunge, the circular railway connects DumDum to BBD Bag & Princep Ghat while suburban railway connects DumDum to north and south suburbs of Calcutta city.

Public transport network of Delhi is being improved and expanded by including a Mass Rapid Transit System, being implemented by Delhi Metro Rail Corporation for a route length of 33 Kms. The commissioning of MRTS corridors is expected to start from December 2002 and all the sections in first phase are likely to be operational by the year 2005.

1.4 NEED OF STUDY

1.4.1 Need for Planning of Bus Transit Network for Large Cities

Large cities require larger movement of people due to three reasons – increase in total volume because of growth in population, rising per capita trip rate and increase in travel distance. Such large scale movements, if carried by personalized modes of transport create congestion on roads, and thus involve high costs, excessive energy consumption, extended journey times, and environmental pollution. Moreover, most of urban residents can-not afford personalized transport. The solution is provision of an efficient public transport system. Efficient, reliable and speedy public transport system constitutes one of the most fundamental needs of urban living and acts as a catalyst to the growth of urban economy. Bus transport in urban centers will continue to form the predominant transport system for the foreseeable future due to its flexible operation, door-to-door service and easy accessibility.

Bus transit network in most of the cities of the developing nations is the outcome of routes generated through 'Destination-oriented approach', which connects Origin and Destination with high demand between them. For small to medium size cities with population less than one million, the routes developed with this approach cater to the generated trips reasonably well. As the population increases, the cities develop in haphazard manner in all directions from the Central Business District (CBD) area. The trips generated from the outskirts of the city area increases enormously. To satisfy the demand matrix that is generated due to the dynamic changes in the city structure, the existing routes are tampered, generally to the convenience of the operators. Tampering of the existing routes leads to zigzag routes passing through different stops enroute. These routes overlap over certain corridors resulting in bunching on certain sections of the bus transit network. High concentration of buses on certain sections of the network and very few on others causes irregular distribution of headways on stops of the routes. Poor operational characteristics with increased complexity are the peculiar characteristics of such type of bus transit network.

It is therefore, urgently, required to design the bus transit network for large cities on scientific basis with a different approach to minimize the limitations encountered with 'Destination-oriented' approach. Hub and spokes system, which relies heavily on 'Direction- oriented' approach, is ideally suited for transit networks of large cities. Hubs generating heavy demand and widely spread over the city area are connected to each other through inter-hub routes. These may be converted to high demand corridors of rapid rail transit system, as the city size assumes the shape of a metropolis. The shorter distances within the influence area of the hubs can be connected through spoke routes.

1.4.2 Need for Integration of MRTS with Bus Transit System

Due to heavy increase of commuters and lack of co-ordination between bus network and railway system in different metropolitan cities in India, considerable increase in intermediate and private transport has taken place. The limited space and heavy growth in traffic has resulted into traffic congestion, reduced travel speed and poor level of service. A large number of commuters are forced to walk for longer distances from railway stations to their destinations. The efficiency of trains and public buses can be enhanced by co-ordinating the two systems so that both work as complimentary to each other instead of competing. A poor co-ordinated transfer leads to long, irregular wait for infrequent connecting services. Information is rarely available at inter-nodal points regarding schedules or connecting services. Transfer also enhances operational efficiency by segmenting an overall system into number of smaller intersecting operational components. The point of balance between the traveler's demand for direct services and the transit operator's need for economy often lies with the level of attention given to the details of the transfer movement. Unfortunately, due to lack of co-ordination, individual's travel time and out of vehicle time is excessively high, which leads to commuter dissatisfaction. If bus transit network and railway system are co-ordinated effectively; it will lead to a well-integrated system.

1.5 OBJECTIVES OF THE STUDY

From the above discussion, it is amply clear that as the city size grows, certain corridors in the city have to cater very heavy demand. The bus transit system planned according to 'Destination-oriented' approach is unable to optimally handle the demand of trip makers. A proper scientific planning and methodology for design of bus transit network for large cities is the need of the hour. As the population increases and the city metamorphosis into metropolis, the bus transit system may not have the capacity to handle the demand of trip-makers; the Mass Rapid Transit System has to be provided. But without operational integration, the higher occupancy level of Mass Rapid Transit System cannot be achieved. To integrate the rail based transit system with the road system, a proper methodology is to be evolved and a Decision Support System for planning of feeder bus network needs to be developed. The objectives of the study can be broadly defined as:

(i) To evolve a methodology for design of Bus Transit Network for large cities based on Hub and Spoke System.

(ii) To develop a Decision Support System for routing, scheduling of feeder bus routes for MRTS and to restructure the existing bus routes.

The above objectives will involve development of a series of models and it is proposed to apply the developed systems for New Delhi, the capital city of India.

Delhi has experienced a significant high growth of population since independence and its urban population is about ninety percent of total population. The public transport system of Delhi is primarily road based catering to a daily demand of about 7.7 million passengers, which is 62 percent of the total demand. The existing bus transit network, spread over a road length of 1650 Km, has over 1100 bus routes with an operating fleet of over 7000 buses. The existing route network of Delhi, which is 'Destination oriented' with criss-cross routes suffers from numerous operational problems. A new MRTS network for Delhi, covering a route length of 33 Km, is under construction to ease out the public transport problems. The commissioning of MRTS corridors will significantly affect the operation of existing bus transit network and there will also be a great need for operational integration of different public transport modes. Operational integration of

railway system and bus transit system through feeder routes can take care of entire journey of commuters in the metropolitan city.

1.6 ORGANIZATION OF THE THESIS

In this chapter, importance of urban public transport especially for developing countries like India is discussed. The need for planning bus transit network for large cities and integration of bus transit network with rapid transit system in metropolitan cities is emphasized. This has been followed by clearly defined thesis objectives.

Chapter 2 presents a review of past studies. Previous approaches to bus transit network generally deals with the vehicle routing, scheduling and combined routing and scheduling problems for small to medium size transit networks. However, limited effort is available in literature for design of bus transit network for large cities and integration of bus transit network with rail system. The chapter concludes with a discussion of limitations of the previous approaches.

Chapter 3 presents the methodology adopted for planning of bus transit network of large cities. Firstly, the advantages of hub and spoke approach over destination oriented bus transit network are highlighted. This is followed by the proposed design methodology, which involves the models for: Selection of optimal hubs, Estimation of inter-hub and intra-hub demand, Routing for inter-hub and secondary routes, and scheduling for inter-hub and secondary routes.

Chapter 4 deals with the development of Decision Support System of feeder bus routes for mass rapid transit system. This interactive Decision Support System has a series of heuristic optimization models integrated with Geographical Information System.

Chapter 5 deals with the study area of New Delhi for the application of models developed in Chapter 3 and chapter 4. Public transportation system, history of mass rapid transit system and implementation program of MRTS in New Delhi is discussed. The chapter concludes with the field surveys for data acquisition.

Chapter 6 presents the results of models developed for bus transit network on New Delhi. Inter-hub routes and secondary routes generated for the selected hubs are presented. Service frequencies on these routes are discussed. The chapter concludes with the overall summary of bus transit network for New Delhi.

In chapter 7, the development of Decision Support System of feeder routes for Delhi Mass Rapid Transit System is presented. The results obtained from the heuristic models are presented through the maps on Arc-View platform.

The summary, conclusions and recommendations, limitations of research work and recommendations for further research work are finally presented in Chapter 8.

CHAPTER - 2

REVIEW OF PAST STUDIES

2.1 GENERAL

Transportation system is a basic component of an urban area's social, economic and physical structure. Not only does the transportation system provide opportunities for mobility, but over the long term, it influences patterns of growth and level of economic activity through the accessibility it provides to various land uses. An efficient public transportation system is required for urban centers in developing countries for the reasons of environmental problems, energy conservation and traffic congestion. Among various means of public transportation, bus transit is the most popular because of near door-to-door accessibility, flexibility in operation and economic affordability. Most bus transit systems have evolved incrementally, as a result of extension, deletion and re-routing by transit operators often in an ad-hoc manner. In most cases, decisions are made based on operator's experience and knowledge of existing land use, rider-ship and schedule requirements.

According to Ceder and Wilson (1986), the design of bus transit system may be considered as a systematic decision sequence. The process of developing a bus service plan consists of five stages: Network design, frequency setting, timetable development, bus scheduling and driver scheduling as illustrated in Table 2.1. The output of each activity positioned higher in the sequence becomes an important input into lower level decision. In most properties, although all the five elements are included in the process, the bulk of resources is devoted to the last two steps namely bus and driver scheduling.

This is understandable because these two activities are directly reflected in the operating cost and are readily amenable to computer-based procedures. However, the two most fundamental elements, namely, the design of routes and setting of frequencies, which critically determine the system's performance from both the operator and the user point of view, have not been sufficiently investigated because of their inherent complexity and implementation difficulty.

Table 2.1: Bus Planning Process

Independent Inputs	Planning Activity	Output
Demand Data Supply Data Route Performance Indices	Level A Network Design	Route changes New routes Operating Strategies
Subsidy available Buses available Service policies Current patronage	Level B Setting Frequencies	Service frequencies
Demand by time of day Times for first & last trips Running times	Level C Timetable Development	Trip departure times Trip arrival times
Deadhead Times Recovery times Schedule constraints Cost structure	Level D Bus scheduling	Bus schedules
Driver work rules Run cost structure	Level E Driver scheduling	Driver schedules

Source: Ceder and Wilson, 1986

2.2 BUS TRANSIT NETWORK DESIGN PROBLEM

In the generalized bus transit network design problem suggested by Bajj and Mahmassani (1991), one seeks to determine a configuration, consisting of a set of transit routes and associated frequencies that achieve some desired objective subject to the constraints of the problem. Mathematical formulations of the bus network design problem have been

ɔncerned primarily with the minimization of overall cost measure, generally ɔmbination of user and operator costs. The former is often captured by the total travel me incurred by the users in the network, while a proxy for the operator cost is the total umber of buses required for a particular configuration. Feasibility Constraints may ıclude:

(a) Minimum operating frequencies on all selected routes,
(b) a maximum load factor on every bus route,
(c) a maximum allowable bus fleet size,
(d) a maximum and minimum limit on route length.

generalized mathematical program for the bus transit network design problem may be iven as follows:

)bjective:	Minimize	$[C1 \times \Sigma\Sigma dem_{ij}(t_{inv,ij}+t_{wt,ij}+t_{tr,ij})+C2\times NBB]$	
ubject to:	Frequency Feasibility	$f_r \geq f_{min}$	$\forall\ r \in SR$
	Route length constraint	$LL_{min} \leq LL_r \leq LL_{max}$	$\forall\ r \in SR$
	Load Feasibility	$CAP \times f_r \geq (q_{ij})^r_{max}$	$\forall\ r \in SR$
	Fleet size constraint	$\Sigma N_r = [\Sigma(f_r \times T_r)] \leq W$	

/here

em_{ij} - Demand between node pair i,j

$_{nv,ij}$ - In-vehicle time between node pair i,j

$_{vt,ij}$ - waiting time incurred between node pair i,j

$_{r,ij}$ - Transfer time incurred between node pair i,j.

IP_r - No. of buses plying on route r, $NP_r = f_r \times R\_T\_T_r$

- Frequency of buses operating on route r

$_{nin}$ - Minimum frequency of buses

$.L_r$ - Length of route r

$.L_{min}$ - Minimum length constraint

$.L_{max}$ - Maximum length constraint

$\_T\_T_r$ - Round trip time of route r

V - Fleet size available for operation

IBB - Number of buses required to operate the system

$(q_{ij})^r_{max}$ - Maximum flow occurring on any link of route r

CAP - Capacity of buses operating on the network

SR - Set of transit routes

C1 - Cost of one passenger-hour of travel time

C2 - Cost of one bus (including capital and operating cost over time period).

In the above formulation, conversion of operator cost into monetary units is not very difficult, but the conversion of user cost into monetary units is rather tricky. Therefore, the kind of trade-off represented by the sum (C1 X user cost + C2 X operator cost), is not really known and is a rather disputed criterion index.

2.3 COMPLEXITIES & COMPUTATIONAL BURDEN OF BUS TRANSIT NETWORK DESIGN PROBLEM

Baaj (1991) pointed out five main sources of complexities as mentioned below that preclude finding a unique optimal solution for the bus transit network design problem.

i) Problem Formulation

Though the minimization of generalized cost is sound objective for the fixed demand formulation, it is difficult to combine user cost (walk time, wait time, ride time, transfer time and number of transfers) and operator cost (fleet size, fixed cost and cost of operation) into a single metric. While the frequency of buses do appear in the problem formulation, the number of routes and their nodal composition do not. The formulation of operator cost constraint also gets to the very heart of difficulty of the problem: Impracticality of evaluating the network without defining the vehicle requirement on each route.

ii) Non-Linearity and Non-convexities

Most formulations of the bus transit network design problem exhibit non-linearities and non-convexities. The objective function and load feasibility constraint are non-linear. Non-convexities are illustrated by the fact that more buses can be deployed without decreasing (or even increasing) total travel time. As pointed out by Newell (1979),

concavity is induced by the waiting time, which occurs at entrance to the system or at transfer points. It is not cost associated with the links of the transit network.

iii) Combinatorial Complexity

This arises from the discrete nature of route design problem and makes it NP-hard. Linstra and Rinnooy kan (1981) have proved that both vehicle routing and scheduling problems are NP-hard. The complexity and computational burden of the problem grow exponentially with the size of the transit network. If more routes exist one has to play with more buses and frequencies.

iv) Multi-objective nature of problem

In the past, most approaches have recognized reducing user costs and / operator costs as their sole objective. In practice, important trade-offs among other conflicting objectives need to be addressed in what is inherently a multi-objective problem. The total demand satisfied and its components (for total demand satisfied directly, via one transfer, via two transfers, or unsatisfied) are examined against the total travel time and its components (the total travel time that is in-vehicle, waiting, or transferring) and against the fleet size required to operate the transit system.

v) Spatial layout of routes

Most past approaches did not identify what constitutes acceptable and good spatial layout of routes. To design an acceptable and operationally feasible set of routes the need to address important design criteria such as route coverage, route duplication, route length and directness of service (circuity). This spatial layout of route system also poses complexity for network design.

2.4 REVIEW OF PAST STUDIES RELATED TO BUS TRANSIT NETWORK DESIGN PROBLEMS

Past studies related to bus transit network design problem can be broadly classified into the following categories.

(a) Vehicle Routing Approaches

(b) Bus Scheduling Approaches

(c) Combined Routing and Scheduling Problems

(d) Routing and Scheduling for integrated Operations

2.4.1 Vehicle Routing Approaches

Due to relatively unconstrained nature of these problems and their inherent complexity, they have tantalized and challenged combinatorial analysts and operation researchers for many years. Researchers have attempted to solve the vehicle routing Problems using different techniques. These techniques can be broadly classified under following categories.

(i) Analytical/Mathematical programming techniques

(ii) Heuristic techniques

(iii)Non-conventional optimization techniques

(iv) Other approaches

2.4.1.1 Analytical/Mathematical Programming Techniques

Byrne (1975) proposed a method of optimal network design assuming a circular city of given radius and for the case, in which the population density varies only with distance from the center. He derived a solution for the optimal number of radial routes by balancing the cost of access against the cost of operation. Chariqui (1975) attempted to treat routes as common lines, which may be a more realistic approach for a large urban area where routes are overlapping and may not be analysed as in individual routes. The problem is formulated as an optimization problem within a probabilistic context, using perceived travel time. Black A. (1978) model is based on a circular city with a definite center and based on population declining uniformly from the center in all direction according to the negative exponential function. Here, only the trips to or from the center are considered and travel is assumed to occur only in radial and along circumference direction. The objective of the model includes travel time, operating costs, equipment and constructions.

Oudhensden (1986) suggested a computerized approach in terms of demand situation in selecting the route design problem. According to him, two standard models can solve the route design problem, the set covering problem (SCP) and the simple plant location problem (SPLP). The SCP model treats the bus route design problem as selecting the best set of routes out of a set of potential routes by considering a single objective. The Objective function is the selected routes should cover at least a pre-specified minimum percentage of the total demand such that the total cost of setting up and operating this transportation system is minimized. In the case of SPLP model, due to the variable demand the bus rider ship will vary with the level of service and this will affect the operator's income. Bus route design can be formulated as a problem where a set of routes must be selected which minimizes the net cost (or maximizes total profit) of the operator. Speiss and Florian (1989) presented a model in which, a set of rules for the selection of bus routes that forms a path to the traveler's destination are formulated. A label-setting algorithm solves the optimization problem in this model.

Laporte et al. (1992) considered vehicle routing problem with Stochastic service and travel times, in which vehicles incur a penalty proportional to the duration of their route in excess of a pre-set constant. Three mathematical programming models are presented: a chance-constrained model is similar to those developed for deterministic vehicle routing problems. Two recourse models were presented: one uses three index variables and can be solved by means of a constraint relaxation algorithm. Computational results indicate that the second model can be used for the exact solution of moderate size problems.

Spasovic and Schonfeld (1993) developed a method for determining the optimal length of transit routes that extend radically from the central business district in to low density suburbs. In addition to the route length, the route spacing, headway and stop locations are also optimized. The equations for route length, route spacing, headway and stop spacing that minimizes the sum of operator and user costs are derived analytically for many to one travel patterns with uniform passenger density. The algorithm is applied to rectangular and wedge-shaped urban corridors with uniform and linearly decreasing

passenger densities. The results show that in order to minimize the total cost, the operator cost, user access cost and user wait cost should be equalized.

Ceder A. and Israleli Y. (1998) described a basic construction of the objective functions of the transit network design problem by taking in account both passenger and operator interests. The approach combines the philosophy of the mathematical programming approaches with decision-making techniques in order to allow the user to select from a number of alternatives. The nature of the overall formulation is nonlinear and mixed-integer programming.

Nes Van R. and Bovy P.H.L. (2000) described the importance of Objectives in Urban Transit-Network Design problems. Their research focuses on the key design variables in urban-transit network design - stop spacing and line spacing – and on the influence of the objective on the resulting design values. Fares are considered to be fixed. The main relationship for these design variables is presented and the impact of different objectives is also shown.

The bus transit network problem is combinatorial in nature and presents several sources of non-linearity and non-convexity, which preclude guaranteed optimal solutions by mathematical/optimization techniques.

2.4.1.2 Heuristic Techniques

Heuristic techniques have been very common approach since last three decades. Lampkin and Saalmans (1967), Silman et.al. (1974), Hsu and Surti (1976), Dubosis et. al. (1979), Dhingra (1980), Baaj et. Al. (1990 and 1995) developed desirables routes from initial skeletons. Lampkin and Saalmans (1967) gave a heuristic algorithm to choose a route network. An initial skeleton route of four nodes is taken and other nodes are inserted into skeleton until a complete route is obtained. Hsu and Surti (1976) suggested a method, which maximizes the bus usage (maximizing passenger per kilometers over the route alternatives) through a stepwise construction of routes for which frequencies are not considered.

Silman et. al.(1974) decomposed the problem in two phases. In the first phase for generating desirable set of routes, frequencies and fleet sizes are not considered. In second phase, after generating desirable set of routes, the optimal frequencies for the routes are calculated taking into account the occupancy rate of buses and the fleet size. The objective function for the second phase is a measure of the desirability of the 'route system'. Therefore, the best of several desirable sets of routes are selected in this phase. Dubois and libre (1979) used a two-step 'Evaluation and Optimization' technique for the problem of modifying transportation network so as to fit with existing demand. Three methods have been carried out for grasping the minimization of total travel time or maximizing accessibility under an investment constraint. The algorithms are of the greedy type; two of them are link removal routines, the other being a link addition one.

The studies mentioned above do not consider overlapping routes, stochastic nature of passenger and bus arrivals at the stations, which are mostly prevalent in large urban transport networks. The passenger processing time at the intermediate stations of the routes have also not been considered. Dhingra (1980) used an evaluation procedure to incorporate these additional aspects at a micro level. The evaluation criteria of Passenger-Kilometer, Average Link density, Route Utilization coefficient was used to select the final set of routes. Mandl (1980) Focuses on the acceptability of links, which are then aggregated to form the route. The set of routes is generated without the guidance of the demand matrix, for example, where the demand pattern is radial; one expects a radial set of routes.

Bajj and Mahamassani (1990,1995) developed a TRUST (Transit Routes Analyst) a Lisp program to analyze and evaluate a given set of bus transit routes and associated frequencies. It calculates the percentages of the total demand trips that are able to reach their destination with no transfer, via one transfer, via two transfers or simply cannot be satisfied (with two or fewer transfers). Also computed are several node level and route level descriptors for use in the route network planning and design process.

These Heuristic algorithms are not theoretically rigorous though they can be used for real size transportation networks and are capable of giving near optimal solutions.

2.4.1.3 Non-Conventional Optimization Techniques

Yihua Xiong and Schneider Jerry (1992) used cumulative Genetic Algorithm and Neural Network for Transportation Network Design. According to them discrete transportation network is deficient in two ways. First, the computing time requirements are large, which makes them infeasible for processing large networks. Second, they cannot process multiple criteria simultaneously- that is only one objective value can be optimized in one run. A neural network in the optimal solution search process to replace the trip assignment algorithm for the computation of total travel time is employed. Then neural network is used in combination with genetic algorithm to search for optimal network designs. The original Genetic Algorithm did not work well for the problem. An analysis of its results suggested improvements leading to Cumulative Genetic Algorithm.

Pattnaik et. al (1998) used genetic algorithm in the route network design. The design is done in two phases; first, a set of candidate routes is generated; then the optimum route set is selected using a genetic algorithm. Two coding schemes, namely fixed string length coding and variable string length coding are developed. Fixed string length coding is simple and gives better results, but it requires more computational time. On the other hand, variable string length coding can handle simultaneously selection of the route set size and the set of routes, but this requires complex coding. Kidwai F.A. (1998) also applied genetic algorithm to solve bus transit network design problem. The route design model starts by identifying major passenger carrying corridors for a given transit network and demand matrix. The sets of corridors correspond to different trade-off between user and operator interests. The corridors are aligned along shortest paths and criteria for selection or rejection of a corridor are path length constraint and average route flow value. Once the shortest path corridors carrying a significant flow are identified, a search is made around these corridors for better routes. To test the suitability of other paths (including shortest paths) for optimal route configuration, k-shortest paths are generated

for each corridor terminal node pair and out of k-paths one is selected, which optimize the desired objective.

In Non-conventional techniques, especially in Genetic algorithms, convergence with in a reasonable period is not guaranteed. Further, Genetic algorithm spends most of its time making small improvements to an already acceptable solution. Neural networks require lot of data set for training and again the convergence is not guaranteed within a time period.

2.4.1.4 Other Approaches

Rapp et. al. (1972) used Interactive Graphic approach and developed a person computer interactive graphics system for optimizing the routing structure on an urban transit network. The computer predicts the effects of routing structure by assigning potential transit trips to the network, and it displays the route loading along with statistics on travel times, rolling stock, and operating costs. The knowledge of experts, rules, facts are required for making a decision. Such gathered information was used for development of user interactive model. Fisher (1994) proposed a methodology to find out the optimal solution of vehicle routing problem using minimum k-trees. Laporte (1994) presented a Tabu search heuristic for the vehicle routing problem with capacity and route length restrictions using minimum k-trees. Dashora (1994) used Knowledge- based expert system (KBES) approach to design a bus transit network.

For these approaches an efficient knowledge base is required and it is very difficult to develop a reliable and efficient knowledge base.

2.4.2 Bus Scheduling Approaches

(a) Optimization Approaches

(i) Optimization approaches satisfying single objective

(ii) Optimization approaches satisfying multiple objectives

(b) Other Approaches

2.4.2.1 Optimization Approaches Satisfying Single Objective

Lampkin and Saalmans (1967) formulated a constrained optimization problem for frequency determination. Their objective was to minimize the total travel time for a given fleet size constraint and a random search procedure was used for solution and their approach does not take into account the finite capacity of buses, concept of transfer time and number of transfers. Seshagiri et. al. (1969) developed time tables and schedules for a route with a view to decrease the fixed plus operational cost of the Bombay Electric supply and transport undertaking. Newell (1971) considered dispatching policies for a transportation route, which are applicable for scheduling fleets. The arrival rate of passengers was taken as a smooth function of time typically having one or more peaks. His objective was to determine the dispatch times of vehicles in such a way as to minimize the total waiting time of all the passengers. It is shown that for unlimited vehicle capacity the optimal dispatch rate of vehicles and the number of passengers served per vehicle both vary with time approximately as the square root of the arrival rate of passengers. However, this methodology does not consider overlapping of routes and does not consider the passenger arrivals and bus arrivals at stations as stochastic in nature.

Rea (1972) presented a model which search for an optimal bus network by adjusting iteratively the frequencies and types of buses on each link to correspond to the link flow level, such that the service on some links is enhanced whilst on others it is depleted. The optimal solution is reached when no further change in link service levels is detected. Scheele (1977) proposed a mathematical programming algorithm of the compound minimization type for bus traffic model. LeBlank (1988) formulated a transit network design model for determining frequencies of each transit line in a network. The objective includes minimizing total auto trips, which is equivalent to maximizing transit usage and weighted sum of the transit line frequencies, so that the multi-modal flows represent a balance between maximizing transit usage and minimizing transit operations cost.

2.4.2.2 Optimization Problems Satisfying Multiple Objectives

Hurdle (1973) found minimum cost schedules for public transit routes. His model considers a route on which each vehicle returns empty to the dispatch point after a round trip time. The arrival rate of passengers is a known deterministic, continuous function of time and the objective is to devise a schedule that minimizes the total cost of passenger waiting time and vehicle operation and for a fleet size, the waiting time of passengers is minimized at a terminus of a route only. Salzborn (1972) determined first the minimum fleet size and then minimized the passenger waiting time for a route using calculus of variation technique. Vehicle movement of a transportation system has been thought of as continuous time dependent flows. Silman et. al. (1974) determined optimum frequencies for a set of bus routes and fleet size, which could minimize the total travel time and discomfort(traveling without a seat). The objective function was minimized by gradient projection method. Dubois et. al. (1979) used a two step procedure in which for a given set of routes and frequencies, various characterization indices are computed and according to index values some frequencies are computed through gradient search approach until convergence of frequencies occurs.

Sengupta and Gupta (1980) developed a set of non-linear programming models to determine an optimal vehicle-mix and fleet selection. Stochastic aspects of travel demand are handled through some formulations of stochastic programming. Furth and Wilson (1981) developed a model, which allocates the available buses between time periods and between routes so as to maximize net social benefit subject to constraint on total subsidy, fleet size, policy headway and levels of vehicle loading. Han and Wilson (1982) developed a deterministic model that minimizes passenger wait time and crowding level subject to constraints on the number of buses available and the provision of enough capacity on each route to carry all passengers selecting it. Hendrickson (1982) maximize the sum of operator profit and net user benefit subject to spacing between parallel routes, the route headway and the fare.

Potvin Jean et.al. (1993) described a technique based on linear programming, which is aimed at appropriately weighting the various criteria (incremental weight learning

scheme) involved in the decision process of an expert vehicle dispatcher. Chakraborty et. al. (1995) used Genetic algorithm based model to minimize the initial waiting time (IWT) of passengers arriving at the station and the transfer time (TT) of passengers transferring at the station subject to fleet size, minimum stopping time at a stop, maximum stopping time, and minimum and maximum transfer time at a transfer station. Model considered only one transfer stop. Patnaik and Tom(1998) used Genetic algorithm based model for urban bus transit network design and calculated associated frequencies for the given set of routes. Kidwai F.A (1998) also used Genetic algorithm. In bilevel Optimization problem, firstly optimal frequencies based on route's maximum link flow are work out iteratively. Upon convergence, the output quantities of interest are frequency of buses on each route, number of buses on each route and base fleet size. In the second level optimization, an attempt is made to reduce the fleet size below the base size by utilizing the fact that routes overlap among themselves.

Banihashemi Mohamadreza and Haghani Ali (2000) presented a procedure for solving real-world large-scale multiple depot vehicle scheduling (MDVS) problems considering the route time constraints (RTCs). According to them, MDVS problems with RTCs (MDVSRTC) can be formulated as an integer-programming problem and the objective function of a MDVSRTC problem is usually minimizing a combination of the capital or fixed cost(as determined by the number of vehicles used) and the total deadhead cost. Application of the proposed procedures in solving bus scheduling procedure in large cities requires a reduction in size of those problems in terms of number of variables and constraints. Two techniques are also proposed to decrease the size of the real-world problems. Combining these techniques results in a strategy to reduce the MTA problem size into a manageable and solvable size.

2.4.2.3 Other Approaches

Dhingra (1980) developed a detailed simulation approach to simulate the flow of passengers on all the nodes of the network and the movement of vehicles on all the routes thereby taking into account the interaction effects of overlapping, crossing, merging and diverging routes. The model takes into account the nature of stochastic nature of

passenger arrivals. Ball M. and Bodin (1983) used Graph partitioning approach. Ceder Avishai (1984) described and analysed several appropriate data collection approaches to set the bus frequencies/headway efficiently. Four different methods are presented to derive the bus frequencies: two are based on point check (maximum load) data and two propose the use of ride check (load profile data).

Mizokami et. al (1986) used Demand performance equilibrium approach. Santhakumar (1987) used a computer simulation model to evaluate the performance of an urban bus route. The impact of various transportation system management (TSM) measures can be predicted enabling the planner to carry out experiments on the computer and arrival at optimal strategies before implementing them. Dashora (1994) used an expert system approach, which allocates the buses to different routes between a minimum and maximum number, based on additional bus allocation factor (Saving in waiting time / additional cost of operation) criteria.

2.4.3.Combined Routing and Scheduling Problems

Hasselstorm (1981) used a Complex two level optimization model, which first reduces the network by eliminating links that are seldom or never used by the passengers. A large set of routes is then generated from the remaining links. Finally the network routes are selected by assigning frequencies using a linear programming model, which maximizes the number of transfers saved by changing from a link network to a public transport network. Kocur and Hedrickson (1982) examined the optimal design of the bus transit in a sub area of a city. The key design variables considered are the distance between parallel bus routes, the frequency of service on a route and the fare. Three different objective functions are treated, ranging from profit maximization to maximization of profit plus some fraction of net user benefit subject to deficit constraint. Optimal line spacing and headway are found to be proportional to one another for all objective functions and constraints examined.

Marwah et.al.(1984) suggested a method which is intended to (a) concentrate the flow of passengers on the road network in such a way that the sum of passenger riding-time cost

and operation cost is minimized (b) to generate a large set of possible bus routes that satisfy certain constraints, and (c) to simultaneously select the routes and their frequencies so that the number of transfers saved in the network is maximized. Heuristics are used for the concentration of flow and generation of routes, and linear programming is used to select routes and frequencies. Ceder and Wilson(1986) presented a two level methodological approach. Level I considers just the passenger view point and level II presents a more challenging developmental effort; however it deals with passenger and operator objectives and therefore increases the probability that the recommended route changes or network design will be accepted. Main objective function of the model presented by Ven Nes et.al.(1988) is to maximize the number of passengers, which gives minimum transfers. The objective to maximize the number of direct trips without transfer does not give due importance to demand satisfied. Each transfer should be given appropriate penalty; routes should be with in some maximum and minimum length for realistic scheduling.

2.5 ROUTING AND SCHEDULING FOR INTERGRATED OPERATIONS

There has been a lot many research works done in area of routing, scheduling and combined routing and scheduling. The effort is meager in the area of co-ordinating the two modes. Most of the work is limited for development of analytical models and for co-ordination at transfer points/terminals.

2.5.1 Models for Feeder Bus Networks

Byrne and Vuchic(1972) determined the optimal locations of a system of parallel bus routes serving a single rail line and the operating frequencies on different parallel routes. Hurdle(1973) extended Byrne and vuchic's work to the case of demand that varied with location and time. Byrne(1976) also extended Byrne and vuchic's work allowing differences in bus operating speed on different parallel routes. Wirasinghe (1977) developed simple linear cost functions for the transit systems. The assignment of buses, between the CBD and an arbitrarily spaced set of rail stations that minimizes the sum of the costs to the commuters and transit operators is determined. The special cases when

the stations are optimally spaced equally spaced and when the railway is replaced by a bus way are discussed.

Wirasinghe(1980) considered a rectangular street network with a rail line parallel to one (x) axis. Feeder buses operate on some of the roads parallel to the other (y) axis. The headways between trains are considered sufficiently small so that the feeder-bus and rail timetables do not have to be synchronized. Nearly optimal feeder bus route location, feeder bus headway on each route and rail station locations is found to minimize the sum of the related travel time costs and the transit operating costs (total cost) and relationships between the transit system parameters and the demand for transit, operating costs etc. have been obtained. Geok and perl (1988) presented a model, which combines three major design variables, bus route spacing, operating headway and bus stop spacing. The optimal route spacing and headway are shown to be cubic root functions of the various parameters. With regard to stop spacing, three different cases are considered: uniform spacing; constant spacing along routes and variable spacing. The optimal stop spacing is shown to be a square root function of the relevant system parameter; it increases with walking speed, value of riding time and average time lost at a bus stop, and decreases with the value of walking time. In the first two cases, the optimal spacing is obtained in closed form as a function of the square root of average trip length. In the case of variable spacing, the optimal stop spacing depends on initial condition like stop spacing etc.
The analytical models developed by Wirasinghe, Geok and Perl consider a highway grid, which is assumed to be rectangular and parallel to a single railway line which may not always be true in practice. They have made an attempt to describe complex system by an approximate analytical model. In the real life various parameters are to be looked into like fleet size, level of service and optimization of transfer timē etc. Their models can be considered as a good exercise to give some initial ideas for one who attempts real life co-ordination problem.

Shrivastava and Dhingra (2001) proposed a heuristic feeder route generation algorithm (HFRGA), which uses different node selection and insertion strategies and is heavily guarded by demand matrix similar to Baaj and Mahamassani (1995). Feeder routes are

developed under the two types of time criteria whose ranges can be set to appropriate values as decided by the designer: (1) maximum demand-deviated shorter time-path criterion; and (2) path extension time criterion.

For co-ordinated transfer optimization is one of the important parameter. Most of the research work on schedule co-ordination is limited for terminals or a particular transfer point.

2.5.2 Models Developed for Schedule Coordination

Bookbinder(1992) employed a simulation model in combination with an optimization model. The model takes randomness of bus travel times into account and optimizes transfers according to various objective functions and under various holding policies. The model assumes constant headway along a given line. This allows a timetable to be described only into two pieces of data, the headway and offset time. Kikuchi and Parmeswaran(1993) introduced a fuzzy control method to co-ordinate the schedules of arrivals and departures of vehicles at a large transportation terminal, such as at a hub terminal of an airline or a timed-transfer bus terminal. The proposed method is fuzzy rule-based method, and it is capable of incorporating many problems-specific constraints. A definite advantage of this method is that many route specific requirements such as varying lay over times due to regulatory requirements of vehicle inspection and repair times and other restrictions can be included in the rules.

Kurt et.al. (1994), optimized the holding time for each ready vehicle for real-time dispatching control in transit terminals on the basis of predicted arrival delays of late vehicles and other factors such as expected transfer volumes and vehicle operating cost. Holding times for each ready vehicle are optimized with the proposed numerical approach, which evaluates the dispatching decision at frequent intervals for ready vehicles by evaluating a dispatching objective function. Shih et. al.(1997) presented trip assignment model for timed-transfer transit systems in which routes are coordinated and scheduled to arrive at transfer stations within pre-set time windows. A general trip assignment model is proposed that apply different assignment rules for three types of

transfer terminals: uncoordinated operations terminals, coordinated operations terminals with common headway for all routes, and coordinated operations terminals with integer-ratio headway for all routes. In addition, the care of missed connections at transfer terminals (due to vehicles arriving behind schedule) is accounted for.

Shih et. al.(1998) presented a heuristic model for the design of bus transit networks with coordinated operations. This model addresses the design of transit networks with coordinated operations, using a transit center concept and incorporating a trip assignment model explicitly developed for coordinated (timed-transfer) systems. In addition, this model determines the appropriate vehicle size for each bus route and incorporates demand-responsive capabilities to meet demand that cannot be served effectively by fixed-route, fixed schedule services.

2.6 LIMITATIONS OF EXISTING APPROACHES

Different existing approaches fail to provide planners with a handy and powerful tool in the following aspects.

- The mathematical programming approach is theoretically rigorous but fails to handle any network of realistic size.
- Simulation of the transit system, though a powerful tool, has been restricted mostly to individual routes or small size transit network.
- Knowledge based expert system approach for routing and scheduling problems involves capturing the domain knowledge of one or more experts and using it to structure to a knowledge base, which can be used to obtain an efficient transit network design. But, the major task is to translate the knowledge and experience about designing transit system into a well-structured knowledge base. The major draw back in this method is an efficient knowledge base is required to be developed by using knowledge of domain experts, facts, rules etc. Collection of actual knowledge is extremely difficult.
- In Non-conventional techniques, especially in Genetic algorithms, convergence with in a reasonable period is not guaranteed and genetic algorithm spends most of its time making small improvements to an already acceptable solution. Neural

networks require lot of data set for training and again the convergence is not guaranteed within a time period. Further, the application of genetic algorithm and neural networks on real life large networks is also a debatable issue.

Heuristic interactive graphic method that allows online interaction between the user and machine can be successfully employed in transit network design for large real life networks. Therefore, Heuristic methods that employ empirically derived rules for near optimal solutions are attempted in this research work for the design of bus transit network and designing of feeder routes.

2.7 SUMMARY

In this chapter, past studies related to bus transit networks and integration of bus system with rail transit is discussed. The bus planning process consists of five stages, where design of routes and setting of frequencies critically determine the system's performance. Bus transit network design is a combinatorial optimization problem involving non-linearity, non-convexity with multiple objective functions. Most of the past studies deal in routing and scheduling of bus transit networks of small to medium size cities, where routes have been constructed through destination-oriented approach. The effort is limited in case of large cities of metropolitan status. For integrated operations of bus transit network with rail system, the analytical or mathematically modeling may not be capable to incorporate the real life constraints and objectives. Very few studies have been reported in the literature for routing and scheduling of integrated operations. Some of these studies involve non-conventional techniques like Genetic algorithms and neural networks. These techniques though analytically optimizes the system but their applicability and adaptability to real life integrated operations desires much more and leaves a big question mark on their application. Heuristic modeling is the best solution for such types of problems and is therefore suggested for the bus transit network problem and integrated operations in this research work.

CHAPTER – 3

METHODOLOGY FOR PLANNING OF BUS TRANSIT NETWORK OF LARGE CITY

3.1 INTRODUCTION

In most of the cities in developing countries, the bus routes evolved are generally destination oriented, which provide services between important stops. In the design methodology for planning such type of routes, origin and destination (OD) node pairs with high demand between them are considered and paths are generated based on certain criteria, taking care of user and operator's cost. With the rapid urbanization in the recent past, the cities are developing away from the central business district (CBD) area and the travel pattern of commuters is changing drastically. Due to the tremendous demand from the outskirts of the city to the major terminals within the CBD area, the destination oriented design methodology results in very long bus routes. Further, to satisfy the desired demand pattern due to the haphazard development of cities in all directions away from the CBD area, a very large number of bus routes are evolved. This makes the bus transit network too complex to be handled. These zig-zag routes overlap on certain corridors resulting in bunching on various sections of the network. This bunching leads to high concentration of buses, thereby causing irregular distribution of headways on the stops of the route. At a certain minimum level of service, extreme variation of headways on stops of a route provide poor operational characteristics like lower load factor. This type of bus transit network in metropolitan city is very complex to understand by commuters and also difficult to operate.

To minimize some of the major limitations encountered in the destination oriented bus routes, the large networks in a city area need to be designed on a different approach. Hub and spoke system, which combines the traditional destination oriented approach along with direction-oriented approach, is ideally suited for such type of large networks. In hub and spoke system, the important terminals of the network constitute the hubs and are widely spread over the network. These hubs are inter-connected with each other through direction-oriented routes basically termed as inter-hub routes. Hubs are surrounded by stops within a certain geographical area, generally known as influence area of hubs. Stops within influence area can be connected to each other based on certain constraints of demand and length or to the hubs through secondary routes. Commuters with large trip length can avail the facility of inter-hub routes along with secondary routes. For shorter trip lengths within the influence area of a hub, only secondary routes can serve the purpose.

Hub and spoke bus system for a large city may have the following advantages as compared to destination-oriented bus system.

(i) Inter-hub routes, interconnecting the hubs, are reasonably direct and avoid unnecessary meandering as has to be resorted in destination-oriented routes. This facilitates reduced travel time between hubs.

(ii) Inter-hub routes passing over a corridor are reasonably limited in number, each having a high frequency of travel. Headways on stops of these routes could be structured to avoid bunching.

(iii) Connectivity to almost all stops of network can be achieved for large networks as each OD pair can be connected either through secondary route or with the combination of secondary route and inter-hub route. In destination-oriented approach, it is quite possible that some of the OD pairs may remain unconnected even after two transfers of routes.

(iv) The system is simple to understand by the users and also relatively convenient from operator point of view for large networks.

(v) Hub and spoke system is adaptable to changes occurring to city structure by ribbon development or so. Introducing more hubs and providing more inter-

hub routes at later stages with the dynamic development of city is quite possible. Whereas, in destination oriented approach the changes in route structure with the passage of time and increased demand are incorporated to the convenience of operator, thereby, making the system more chaotic.

(vi) With the dynamic changes in the city structure and increase in population of the large cities, the inter-hub routes identified under hub and spoke system can be planned as major corridors of rapid transit system at a later stage.

3.2 STUDY METHODOLOGY

In light of the above discussion, it is proposed to evolve a methodology for designing a large bus transit network based on hub and spoke system. This system has the following components.

- Hubs – These are the major terminals of the transit network and spread out over the entire city area.
- Influence Area – Each hub has a certain geographical area containing stops from where the commuters may be attracted to the hubs.
- Inter-Hub routes – These are the high frequency, reasonably direct routes which connect different hubs.
- Secondary routes – These routes provide connectivity of the hub with the stops in its influence area.

Taking account of these components, the design methodology for planning of Hub and Spoke bus transit network design is shown in Figure 3.1 and involves the following stages.

(i) Selection of optimal Hubs and delineation of Influence area for each Hub
(ii) Estimation of Inter-hub and Intra-hub demand
(iii) Generation of the path for Inter-Hub routes
(iv) Generation of the path for Secondary routes
(v) Determination of service frequencies for Inter-hub routes
(vi) Determination of service frequencies for secondary routes

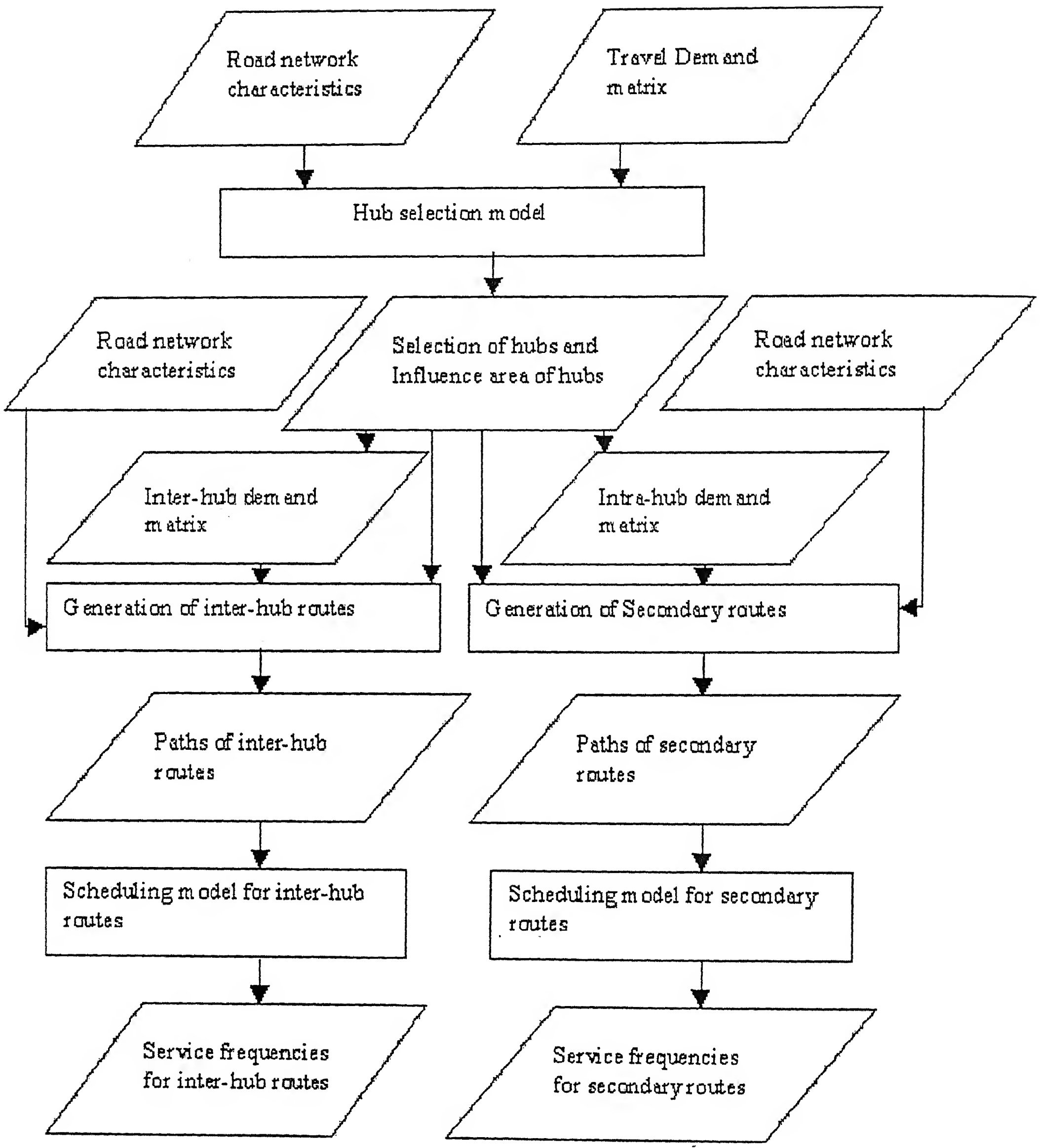


Figure 3.1: Broad Study Methodology of Bus Transit Network

3.2.1 Selection of Optimal Number of Hubs

The whole design process for bus transit system is heavily dependent upon the identification and selection of hubs, it is therefore imperative that this process is to be done judiciously. Though there is no concrete objective function for the identification of hubs among the bus stops, but some of the properties, which a hub should fulfill, are:

- Generate high passenger demand, production as well as attraction.
- Need to provide good transfer opportunities
- Should have sufficient influence area to provide high originating trips emanating from the secondary routes
- Should be away separated from other hubs by a certain minimum travel distance/time.

Past studies on hub location (Baaj, 1998) deal the problem through intitutive procedure or on the basis of user knowledge of distribution of bus stops, the passenger demand at the bus stops and other relevant parameters. In other words, the hubs are handpicked from the distribution of bus stops and passenger demand on an intitutive basis. However such methods has no mathematical basis and therefore may be misleading.

In this work, optimal selection of hubs is attempted through a mathematical model and the objective is to minimize the 'Total Passenger Time' for the Bus Transit System. The general formulation of the problem can be given as

Objective function:

$$\text{Minimize: } \sum_{j=1}^{N}\sum_{i=1}^{N} dem_{ij}\,(t_{tt,ihb1} + t_{tt,hb1hb2} + t_{tt,hb2j} + t_{wt,i} + t_{wt,hb1} + t_{wt,hb2})$$

$$\forall\ i \in Inf_{hb1} \text{ and } \forall\ j \in Inf_{hb2}$$

where

dem_{ij} is demand between node pair (i,j)

$t_{tt,ihb1}$ is travel time between stop 'i' and hub hb_1

$t_{tt,hb1hb2}$ is travel time between hub hb_1 and hub hb_2

$t_{tt,hb2j}$ is travel time between hub hb_2 and stop j

$t_{wt,i}$ is waiting time at stop 'i'

$t_{wt,hb1}$ is waiting time at hub hb_1

$t_{wt,hb2}$ is waiting time at hub hb_2

Inf_{hb1} is influence area of hub hb_1

Inf_{hb2} is influence area of hub hb_2

N is total number of stops.

In the above formulation, the objective function of 'Total Passenger Time' involves the summation of terms, travel time from stop 'i' to hub hb_1, hub hb_1 to hub hb_2, hub hb_2 to stop j and waiting time at stop 'i', hub hb_1, hub hb_2.

The estimation of waiting time at various important stops requires the operational plan of the bus transit system. But at beginning of the design process, it is not possible to have the operational plan; therefore the waiting time calculation is to be done on the basis of policy headways.

In a large city, the number of bus stops is very large and the hubs are to be selected among these stops on the basis of the generated demand as well as the required infrastructure at the stops. The hubs are to be well spread up subject to the certain operational constraints like minimum distance between the hubs. All these considerations lead to a very complex design problem and the computational burden increases enormously. As it may not be possible to obtain the global optimum due to the complexity of the problem and large number of constraints; heuristic models are therefore involved in the design process.

In this study, the location of optimal hubs is generated by the following three-step procedure.

(i) Partitioning of stops in clusters
(ii) Location of hub within a cluster and its influence area.
(iii) Selection of optimal hubs

3.2.1.1 Partitioning of Stops in Clusters

Selection of hubs from a large number of stops in a city network requires that the whole city area be equally represented as far as possible and these hubs should be widely spread out. In this process, the study area is to be divided into a number of zones/clusters. In other words, all the stops of the city network are to be partitioned into a number of clusters. Each cluster will have a number of stops and one of them will be a Hub. The area enclosing the stops within a cluster defines the Influence area of the Hub.

Two clustering methods are introduced in this study to partition the stops into a predefined number of clusters. One method 'Fuzzy-c-means clustering' belongs to the class of fuzzy logic and the other 'Self-organizing-map' is chosen from the neural networks. These clustering methods offer generalized procedure for computing the clusters center and stops present in the clusters. The data set to obtain the stops in the clusters depends on the location of bus stops and the generated demand at the bus stops.

3.2.1.1.1 Fuzzy-C-Means Clustering

Fuzzy C-means clustering is an extremely powerful classification method. Clustering refers to identifying the number of subclasses of c clusters in a data universe Z comprised of N data samples, and partitioning Z into c clusters ($2 \le c < N$).

To introduce this method, we define a set of 'N' bus stops that we wish to classify

$$Z = \{z_1, z_2, z_3, \ldots\ldots\ldots\ldots, z_N\}$$

Each bus stop, z_k is defined by three features i.e x-coordinate, y-coordinate and demand.

$$Z_k = \{z_{k1}, z_{k2}, z_{k3}\}$$

Since the three features all can have different units, in general, we have to normalize each of the features to a unified scale before classification. In a geometric sense, each z_i is a point in three-dimensional feature space, and the universe of the bus stops sample, Z, is a

point set with N elements in the sample space. Bezdek (1981) suggested using an objective function approach for clustering the data into hyper spherical clusters. The objective function is developed so as to do two things simultaneously: First, minimize the Euclidean distance between each data point in a cluster and its cluster center (a calculate point), and second, maximize the Euclidean distance between cluster centers. The objective function takes the form

$$J(Z,U,V) = \sum_{k=1}^{n}\sum_{i=1}^{c}(\mu_{ik})^m \|Z_k - v_i\|^2 \tag{3.1}$$

Where Z is the data set of bus stops consisting of feature vectors z_k, $k = \{0,1,2\}$ and $U = [u_{ik}] \in [0,1]$ is the fuzzy partition matrix of Z and subject to the following constraints:

$$0 \le \sum_{k=1}^{n}\mu_{ik} \le N,\ 1 \le i \le c \tag{3.2}$$

$$\sum_{i=1}^{c}\mu_{ik} = 1,\ 1 \le k \le N \tag{3.3}$$

The vector $V = [\,v_1, v_2, \ldots, v_c]$, $v_i \in R^n$ is a cluster of prototypes (centers), which have to be determine and $d_{ik} = \|\, Z_k - v_i\|^2$ is the squared inner product norm (typically Euclidean) and $m \in [0,\infty]$ is weighting exponent that determines the fuzziness of the resulting clusters.

The basic idea is to find those 'c' locations in the database of bus stops such that the sum of the distances from all the bus stops to those 'c' points is minimized. The term μ_{ik}, which is an element of the partition matrix U, plays a very important role. Without this term the point of minima would simply lie at the mean of the entire distribution of bus stops. If one were to have only one cluster, then the center of cluster would simply be at the mean of the distribution of bus stops i.e.

$$v = \sum_{k=1}^{N} x_k / N$$

Since 'c' such minimum points need to be found without all the point collapsing to the mean, assigning a weight or membership to each cluster for every bus stop becomes mandatory. This is done through μ_{ik}, which denote the membership of bus stops k in cluster 'i'. Assigning Membership values to each bus stop with respect to 'c' centers assures that all the centers do not collapse to the mean of the entire distribution of bus stops. Minimization of the objective function (3.1) with respect to v_i's yields the clusters and minimizing with respect to μ_{ik} yield the optimal membership value of each bus stop in the particular cluster.

The stationary points of the objective function can be found by adjoining the constraint of (3.2) and (3.3) by means of Lagrange multipliers:

$$J_m(Z;U,V,\lambda) = \sum_{k=1}^{n}\sum_{i=1}^{c}(\mu_{ik})^m \|Z_k - v_i\|^2 + \sum_{k=1}^{n}\lambda_k \left[\sum_{i=1}^{c}\mu_{ik} - 1\right] \qquad (3.4)$$

$$\partial j_m / \partial v_i = 0; \qquad \Rightarrow -2\sum_{k=1}^{n}(\mu_{ik})^m (Z_k - v_i) = 0$$

$$\Rightarrow \quad v_i = \frac{\sum_{k=1}^{n}(\mu_{ik})^m Z_k}{\sum_{k=1}^{n}(\mu_{ik})^m} \qquad (3.5)$$

Equation (3.4) can be written as:

$$J_m = \sum_{k=1}^{n}\sum_{i=1}^{c}(\mu_{ik})^m d_{ik}^2 + \sum_{k=1}^{n}\lambda_k \left[\sum_{i=1}^{c}\mu_{ik} - 1\right]$$

$$\partial j_m / \partial \mu_{ik} = 0; \qquad \Rightarrow \quad m(\mu_{ik})^{m-1} d^2_{ik} + \lambda_k = 0 \qquad \Rightarrow \quad (\mu_{ik})^{m-1} = -\lambda_k / md^2_{ik}$$

$$\text{or} \quad \mu_{ik} = [-\lambda_k / md^2_{ik}]^{1/m-1} \qquad (3.6)$$

$$\partial j / \partial \lambda_k = 0 \quad \Rightarrow \quad \sum_{i=1}^{c} \mu_{ik} = 1 \quad \Rightarrow \quad \sum_{i=1}^{c} \left[\frac{-\lambda_k}{m d_{ik}^2} \right]^{\frac{1}{m-1}} = 1$$

$$\Rightarrow \quad (-\lambda_k / m)^{\frac{1}{m-1}} \sum_{i=1}^{c} \left(d_{ik}^{-2} \right)^{\frac{1}{m-1}} = 1$$

$$(-\lambda_k / m)^{\frac{1}{m-1}} = \frac{1}{\sum_{i=1}^{c} (d_{ik}^{-2})^{\frac{1}{m-1}}} \tag{3.7}$$

Substituting $(- \lambda_k / m)^{1/m-1}$ of (3.7) in (3.6) we get;

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c} (1/d_{jk}^2)^{1/m-1} * 1/(d_{ik}^2)^{1/m-1}}$$

$$\mu_{ik} = \frac{1}{\sum_{j=1}^{c} (d_{ik}^2 / d_{jk}^2)^{1/m-1}} \tag{3.8}$$

The algorithm converges to its optimal fuzzy partition matrix and cluster centers through an iterative procedure till the difference in the norm between successive partition matrices is less than a prescribed tolerance ε.

Algorithm

The steps in the algorithm are as follows.

i. Fix c ($2 \leq c < N$) and select a value for parameter m. Initialize the partition matrix, $U^{(0)}$.

Each step in the algorithm will be labeled rx, where rx = 0,1,2....

ii. Calculate the c centers $\{v_i^{(rx)}\}$ for each step.

iii. Update the partition matrix for the rxth step, $U^{(rx)}$ as follows.

$$\mu_{ik}^{(rx+1)} = \left[\sum_{j=1}^{c} (d_{ik}^{(rx)} / d_{jk}^{(rx)})^{2/(m'-1)} \right]^{-1} \quad \text{for } I_k = \phi$$

or $\mu_{ik}^{(rx+1)} = 0$ for all classes I where $i \in I_k$

where $I_k = \{ I \mid 2 \le c < N ; d_{ik}^{(rx)} = 0 \}$

and $I_k = \{ 1,2,\ldots, c \} - I_k$

and $\sum_{i \in I_k} \mu_{ik}^{rx+1} = 1$

iv. If $\| U^{(rx+1)} - U^{(rx)} \| \le \varepsilon$, stop; otherwise set rx = rx + 1 and return to step 2.

The algorithm is applied on the following input.

Input

(i) Number of bus stops N. Each bus stop represents as $Z_k = \{z_{k1}, z_{k2}, z_{k3}\}$ k= 1,2,3,….N. z_{k1} and z_{k2} represents the Cartesian coordinates of the bus stops whereas z_{k3} represents the demand of the bus stops.

(ii) Number of clusters 'c' into which the bus stops is to be partitioned.

Output

The center of each cluster $v_i = \{v_{i1}, v_{i2}, v_{i3}\}$ where each component of v_i has the same connotation as z_i, $1 \le i \le c$.

3.2.1.1.2 Self – Organizing Map

The principal goal of the self-organizing map (SOM) is to transform an incoming signal pattern of arbitrary dimension into a one or two-dimensional discrete map, and to perform this transformation adaptively in a topology conserving fashion. By topology conserving we mean those points, which are near to each other through a certain metric sense in the input space, are also near in the output map. Thus it is said that the map preserves the topology of the input structure. The algorithm responsible for the formation of the self-organizing map proceeds first by initializing the synaptic weights in the network. This can be done by assigning them small values picked from a random number generator, in so doing; no prior order is imposed on the feature map. Once the network has been properly initialized, there are three essential processes involved in the formation of the self-organizing map.

i. Competition: For each input pattern, the neurons in the network compute their respective values of the discriminant function. This discriminant function provides the basis for competition among the neurons. The particular neuron with the largest value of discriminant function is declared winner of the competition.

ii. Cooperation: The winning neuron determines the spatial location of a topological neighborhood of excited neurons, thereby providing the basis for cooperation among such neighboring neurons.

iii. Synaptic Adaptation: This last mechanism enables the excited neurons to increase their individual values of the discriminant function in relation to the input pattern through suitable adjustments applied to their synaptic weights. The adjustments made are such that the response of the winning neuron to the subsequent application of a similar input pattern is enhanced.

The details of the above processes are described as follows.

Competition Process

Let k denote the dimension of the input (data) space. Let an input pattern (vector) selected at random from the input space be denoted by

$$X = [x_1, x_2, \ldots\ldots\ldots, x_k]^T$$

The synaptic weight vector of each neuron in the network has the same dimension as the input space. Let the synaptic weight vector of neuron j be denoted by

$$W_j = [w_{j1}, w_{j2}, \ldots\ldots\ldots\ldots w_{jk}]^T, \qquad j = 1,2,\ldots\ldots,\xi$$

Where, ξ is the total number of neurons in the network. To find the best match of the input vector x with the synaptic weight vectors w_j, compare the inner product $w_j^T x$ for $j = 1,2,\ldots\ldots\xi$ and select the largest. This assumes that the same threshold is applied to all the neurons; the threshold is the negative of bias. Thus, by selecting all the neuron with the largest inner product $w_j^T x$, we will have in effect determined the location where the topological neighborhood of excited neurons is to be centered. The best matching criterion, based on maximizing the inner product $w_j^T x$, is mathematically equivalent to minimizing the Euclidean distance between the vectors x and w_j. If we use the index i(x)

to identify the neuron that best matches the input vector x, we may then determine i(x) by applying the condition

$$i(x) = \arg ||\min x - w_j||, \qquad j = 1,2,\ldots\ldots\xi$$

Which, sums up the essence of competition process among the neurons. The particular neuron i that satisfy this condition is called the best-matching or winning neuron.

Cooperation Process

The winning neuron locates the center of a topological neighborhood of cooperating neurons. Let $h_{j,i}$ denote the topological neighborhood centered on the winning neuron i, and compassing a set of excited (cooperating) neurons, a typical one of which is denoted by j. Let $d_{i,j}$ denote the lateral distance between winning neuron i and excited neuron j. Then we assume that the topological neighborhood $h_{j,i}$ is a uni-modal function of the lateral distance $d_{i,j}$, such that it satisfies two distinct requirements.

- The topological neighborhood $h_{j,i}$ is symmetrical about the maximum point defined by $d_{i,j} = 0$; in other words, it attains its maximum value at the winning neuron i for which the distance $d_{j,i}$ is zero.
- The amplitude of the topological neighborhood $h_{j,i}$ decreases monotonically with increasing lateral distance $d_{j,i}$, decaying to zero for $d_{j,i} \rightarrow \infty$; this is a necessary condition for convergence.

A typical choice of $h_{j,i}$ that satisfies these requirements is the Gaussian function

$$h_{j,i(x)} = \exp(-d^2_{j,i} / 2\sigma^2)$$

Which is translation variant (i.e. independent of location of winning neuron). The parameter σ is the 'effective width' of the topological neighborhood and measures the degree to which excited neurons in the vicinity of the winning neurons participate in the learning process. In a qualitative sense, the gaussian topological neighborhood is more biological appropriate than a rectangular one and its use also make the SOM algorithm converges more quickly. For cooperation among neighboring neurons to hold it is necessary that topological neighborhood h_{ji} be dependent on lateral distance $d_{j,i}$ between winning neuron i and excited neuron j in the output space rather than on some distance measure in the original input space.

Adaptive Process

For the network to be self-organizing, the synaptic weight vector w_j of neuron j in the network is required to change in relation to the input vector x. The change to the weight vector of neuron j in the lattice is

$$\Delta w_j = \eta h_{j,i(x)}(x - w_j)$$

Finally, using discrete-time formalism, given the synaptic weight vector $w_j(nx)$ of neuron j at time nx, the updated weight vector $w_j(nx+1)$ at time nx+1 is defined by

$$w_j(nx+1) = w_j(nx) + \eta(nx)h_{j,i(x)}(nx)(x - w_j(nx))$$

which is applied to all the neurons in the lattice that lie inside the topological neighborhood of winning neuron i. This has the effect of moving the synaptic weight w_i of winning neuron i toward the input vector x. Upon repeated presentations of the training data, the synaptic weight vectors tend to follow the distribution of the input vectors due to the neighborhood updating. The algorithm therefore leads to a topological ordering of the feature map in the input space in the sense that neurons that are adjacent in the lattice will tend to have similar synaptic weight vectors.

Algorithm

The inputs are the number of bus stops n, each represented as $X_k = \{x_{k1}, x_{k2}, x_{k3}\}$, where k = 1,2,......,n are the number of centers that needs to be obtained. The algorithm processes the data by capturing the topology of the input space through a two-dimensional lattice of neurons of size N=ξ1 x ξ2, where ξ1 and ξ2 are the number of neurons in each dimension. The weights of the neuron denote the centers of the clusters from which the terminals will be obtained. The steps of algorithm are as follows.

i. *Initialization:* Choose random values for the initial weight vectors $w_j(0)$. The only restriction here is that the $w_j(0)$ will be different for j = 1,2,...,ξ, where ξ is the number of neurons in the lattice. It may be desirable to keep the magnitude of the weights small. Another way of initializing the algorithm is to select the weight vectors $\{w_j(0)\}^{\xi}_{j=1}$ from the available set of input vectors $\{x_i\}^{n}_{i=1}$ in a random manner.

ii. Sampling: Draw a sample x from the input space with a certain probability; the vector x represents the activation pattern that is applied to the lattice. The dimension of vector x is equal to k.

iii. Similarity Matching: Find the best matching (winning) neuron i(x) at time step n by using the minimum distance Euclidean distance criterion:

$$i(x) = \arg ||\min x - w_j||, \qquad j = 1,2,\ldots\ldots\xi.$$

iv. *Updating:* Adjust the synaptic weight vectors of all neurons by using the update formula

$$w_j(nx+1) = w_j(nx) + \eta(nx)h_{j,i(x)}(nx)(x - w_j(nx))$$

where $\eta(nx)$ is the learning rate parameter, and $h_{j,i(x)}(nx)$ is the neighborhood function centered around the winning neuron i(x); both $\eta(nx)$ and $h_{j,i(x)}(nx)$ are varied dynamically during learning for best results.

v. *Annealing:* Decreasing the neighborhood parameter (σ) and learning rate η with time is found to give better results. They are annealed as $\sigma = \sigma_0(1- \omega_0/\omega)$; $\eta=\eta_0(1- \omega_0/\omega)$, where σ_0 and η_0 are the initial values of σ and η, ω is the maximum number of iterations and ω_0 is the current count of iteration. Another formulation for the annealing process $\eta=\eta_0(n_f\ /\ n_0)^{t/T}$; $\sigma=\sigma_0(\sigma_f\ /\sigma_0)^{t/T}$, where σ_f and σ_0 are final and initial value of neighborhood parameter and η_f and η_0 are similarly for learning rates. Decreasing the width of gaussian neighborhood function has a key role in the formation of clusters. Initially a large width involve all the neurons in the lattice to get close to a particular input, however with passage of time as the width of gaussian decreases, clusters of influence are formed and only those within the cluster participate in updation.

vi. *Continuation:* Continue with step 2 until no noticeable changes in the feature map are observed.

3.2.1.2 Location of Hub within a Cluster/Influence Area

Fuzzy-c-means clustering method and Self-organizing-map method partition the stops of the large city network into a number of clusters, each cluster representing some geographical area of the city. Hub is to be located in each cluster from the stops present in the cluster. This is achieved with the objective to minimize the total travel distance (passenger-km) for all stops within a cluster. Mathematically, it can be described as

$$\text{Objective function:}\quad \text{Minimize} \sum_{\substack{all\ stops\ in \\ influence\ area}} dis_{ihb} \times dem_i$$

where dis $_{ihb}$ is shortest distance from stop 'i' to a selected stop 'hb' in the cluster, and dem_i is total generated demand of stop 'i'

Due to the computational complexity for a large network in a metropolitan area, an algorithmic approach is applied for the location of hubs within a selected cluster. For each cluster, five bus stops of highest demand are considered as probable terminal stops or hubs. Due to the high demand, one of them is likely be the optimal choice as a hub. Limiting the choice to five stops will avoid the excessive mathematical computations involved in considering all stops as probable terminals.

Shortest distance between the bus stops of the total transit network is obtained. Choosing one bus stop among these five bus stops as the probable terminal stop, total passenger-km is calculated for all the stops in a cluster. Passenger-km of a stop is the product of the bus stop demand and the shortest distance between bus stop and probable terminal stop. Total Passenger-km is the sum of the passenger-km for all stops in the cluster. The probable terminal stop having minimum total passenger-km will be selected as a hub for the cluster. All the stops in the cluster are bounded in a geographical area, which is defined as the influence area of the selected hub. The same procedure is to be applied for all the clusters and hubs are obtained for the entire network.

3.2.1.3 Selection of Optimal Hubs

In the first two steps described earlier, the transit network of a metropolitan city has been partitioned in a number of predefined clusters; hubs are selected, and influence area has been delineated for each of these clusters. This step aims to select the optimal number of Hubs. For the optimal number, the clusters can be formed, hubs are identified and influence areas delineated. This can then be used for generation of bus routes based on hub and spoke system. Optimum number of clusters is based on minimizing the total passenger travel time of the entire network.

The originating stop and the destination stop for any traveler may lie within the influence area of same cluster or in different clusters of the transit network. When both origin and destination stops lie within the influence area of same cluster, then there is no need of any transfer through the hubs. But if the origin and destination stops lie in influence areas of different clusters, then a person has to transfer through the hubs.

Travel time for all O-D pairs through Hubs are to be estimated for further analysis as shown in Figure 3.2. If the originating stop 'i' and destination stop 'j' are located in the same cluster, then

Travel time (i,j)= Shortest travel time between stop i and j + waiting time at 'i'

and, if the originating and destination bus stops i and j are in different clusters, then

Travel time(i, j)= Shortest travel time between i and hb_1 + Shortest travel time between hb_1 to hb2 + shortest travel time between hb_2 to j + + waiting time at 'i' + waiting time at hb_1 + waiting time at hb_2

Passenger-Time for traveling from bus stop i to j is calculated depending upon whether the originating and destination stops lie in the same cluster or in different clusters. Total passenger time for the network is also estimated.

Passenger_Time (i,j) = Int_stop_demand (i,j) * Travel Time (i,j)

$$\text{Total Passenger\_Time} = \sum_i \sum_j Passenger\_Time(i, j)$$

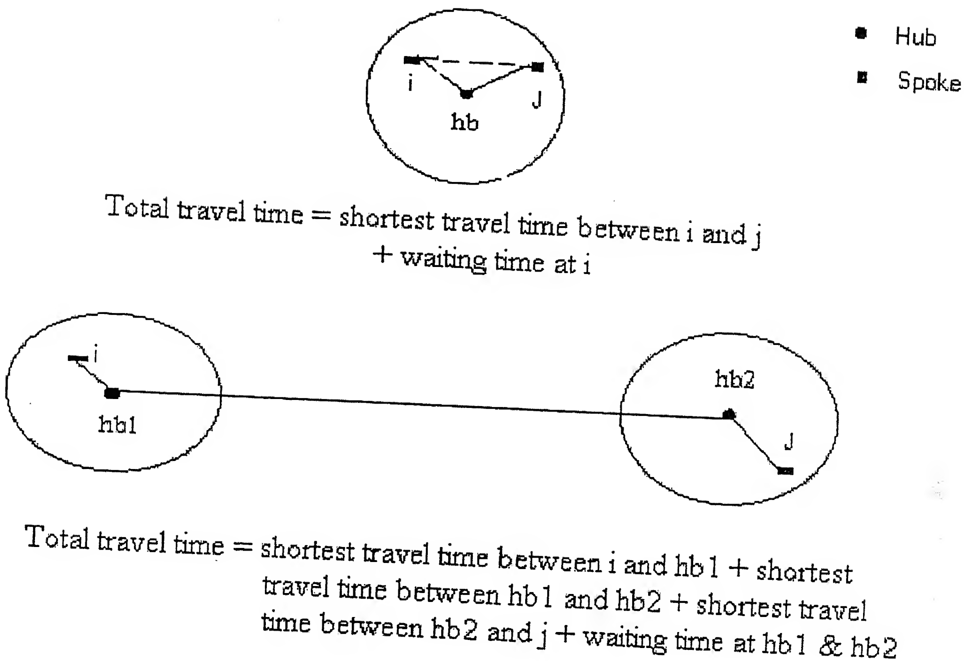


Figure 3.2: Total Travel Time for OD pairs

The set of clusters, which provide the minimum 'Total Passenger Time', is treated as the optimum number of clusters/hubs for the entire bus transit network.

3.2.2 Estimation of Demand for Bus Transit Network

Hub and spokes bus transit system consists of two types of routes, inter-hub routes and intra-hub routes (Spoke or Secondary routes). To generate these two types of routes, the inter-stop demand matrix is adjusted to estimate the following two demand matrices.

(i) Inter-hub demand matrix

(ii) Intra-hub demand matrix

Inter – hub demand matrix represents the estimated demand between the hubs and is of interest in planning inter-hub routes. Considering a stop pairs (i and j), where these stops lie in the influence areas of different hubs hb1 and hb2, then the total demand obtained

from such node pairs lying in the influence area of a particular hub will be accumulated on the hub. Similar will be the case for the demand on other hub.

$$\text{Inter\_hub\_demand (hb1,hb2)} = \sum_j \sum_i \text{int\_}stop\_dem(i,j)$$

for $i \in Inf_{hb1}$ and $j \in Inf_{hb2}$

where Inf_{hb1} and Inf_{hb2} are the influence areas of hub hb1 and hb2 respectively.

The intra hub demand matrix consists of demand obtained from two components.

(i) Feeder demand: The demand of stops lying in the influence area of a particular hub 'hb' and going to the influence area of some other hub.

$$\text{Feeder\_demand (i,hb)} = \sum_j \text{int\_}stop\_dem(i,j) \quad \text{for } j \notin Inf_{hb}$$

(ii) Demand between stop to stop within the influence area of a hub 'hb'.

$$\text{Intra\_hub\_demand (i,hb)} = \text{feeder\_demand (i,hb)} + \sum_j \text{int\_}stop\_dem(i,j)$$

for $i,j \in Inf_{hb}$

Where Inf_{hb} is influence area of hub 'hb'.

3.2.3 Bus Route Generation Models

Choosing suitable bus routes is the foundation decision in the design of a good transit network. The problem to be addressed can be defined in the following terms: Given the transit demand matrix, a description of the network specifying for each node, its neighbouring nodes and the distance of all connecting links; determine sets of routes that correspond to different trade off between user and operator costs. The problem in the selection of an optimal route set is the lack of any clear criteria as to what is a good network of routes (and what is not). In the absence of a concrete objective function what must be done to select a route system is to think of properties one would expect to be present in a good network of routes and then to produce a model which will ensure that a network designed by the model will have all the properties. Some properties one would expect from a good transit network are

a) Most journeys for which there is appreciable demand should be possible without changing.
b) Routes should be reasonably direct and non-circuitous (no backtracking).
c) Routes should meet to facilitate changing.
d) Routes should neither be too long (they are likely to be unreliable in terms of schedule) nor too short (they are likely to require excessive resources).
e) There should not be too many routes.
f) There should not be too much overlapping of links for different routes.

In the present work, bus route generation models comprise of generation of inter hub routes and secondary routes.

3.2.4 Generation of Inter hub routes

The inter hub routes provide connectivity between the hubs and satisfy high demand. These routes are reasonably direct, have high frequency and high operating speed of the buses. In this model, it is planned that all the hubs are connected to each other with inter-hub routes as far as possible. For a network of 'NH' hubs, a maximum of NH*(NH-1)/2 inter-hub routes can be generated. For a large network, as it may not be feasible to operate on such a large number of generated routes, therefore some operational constraints like minimum inter-hub demand, minimum and maximum route length etc. have been incorporated in the model for the selection of terminal hubs. The terminal hubs are first connected to each other along the shortest path. Meandering along the shortest path generates alternative paths between the two terminal hubs. These alternative paths are evaluated such that the stops/hubs along the generated routes are served in an optimal way. The alternative paths are short-listed using a criterion of 'route utilization coefficient' and the final selection of optimal path is done on the basis of 'Desire-passenger-km per km'.

In this model, inter-hub routes are generated between the terminal hubs and inter-hub demand matrix heavily guides the inter-hub route identification. The model generates the different sets of routes corresponding to different trade-offs among conflicting objectives.

The input data required for generating the inter-hub routes are

i) Network: Layout of the road network and weight matrix. The weight matrix of an N-node network is an N X N matrix. W = $[w_{ij}]$ in which the $(i,j)^{th}$ entry w_{ij} is the weight (distance or in-vehicle time) of (i,j), the link from i to j in the network.

ii) Location of hubs

iii) Inter-hub demand matrix.

The model for generation of inter-hub routes is illustrated in Figure 3.3 and consists of the following steps.

(i) Identification of terminal hubs

(ii) Generation of alternative paths between terminal hubs

(iii) Evaluation of alternative paths by a predefined criteria

(iv) Selection of optimal path

These steps are repeated till most of the inter-hub demand is satisfied.

Step I: Identification of Terminal Hubs

Generation of an inter-hub route requires identification of two terminal hubs subject to the following constraints.

(i) Each hub should have necessary space available for parking of buses.

(ii) The hubs should have considerable demand between them.

(iii) The distance between the two hubs should be such that generated routes are viable from operator point of view. Further, the distance between the two hubs should be within certain limits of maximum distance for the optimal operation of the generated routes.

Pair of terminal hubs satisfying the above constraints, are-selected in the order of the inter-hub demand. The process starts with the pair having the highest demand. After a route path is finally selected, new terminal pair is identified for further generation.

Step II: Generation of Alternative paths between Terminal Hubs

Alternative paths between the two terminating hubs are generated. The first alternative path is generally taken to be the shortest path. Besides the shortest generated path, a

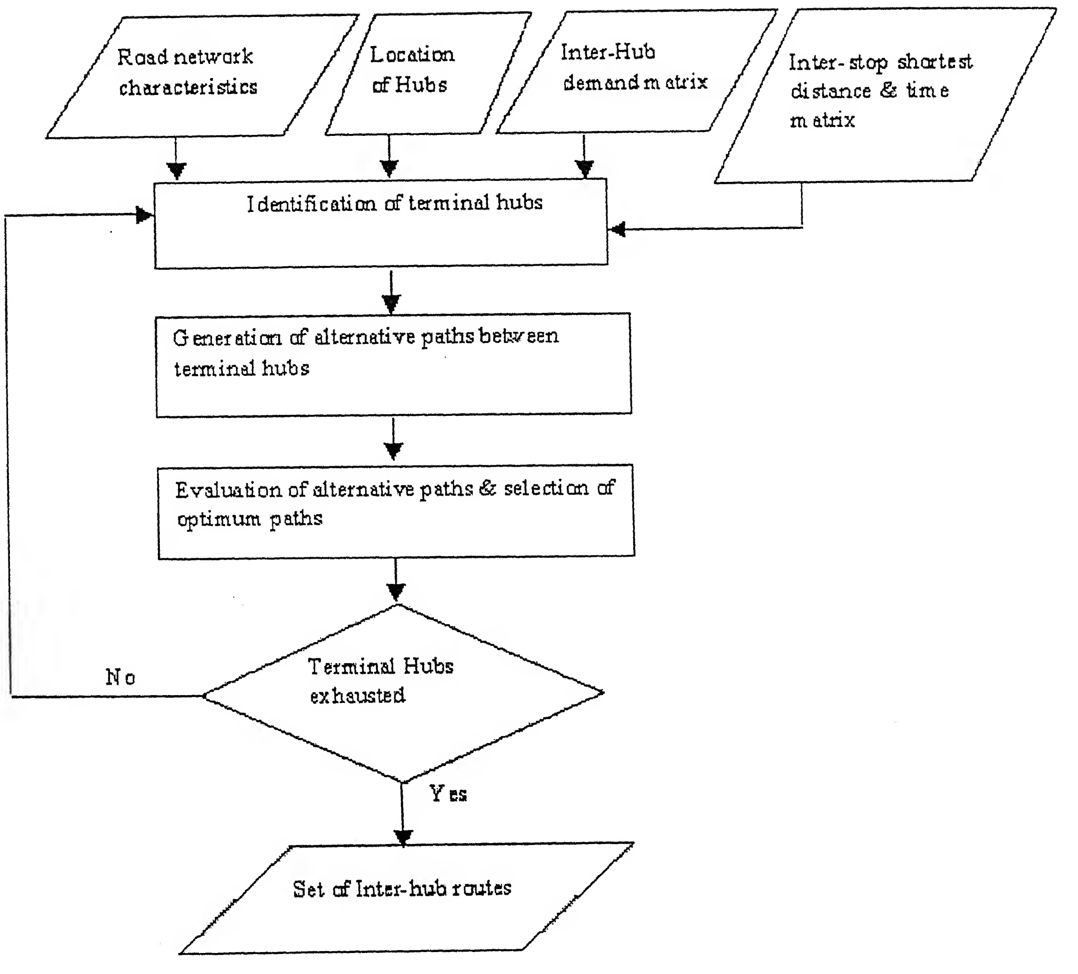


Figure 3.3: Routing Model for Inter-Hub Routes

number of other alternative paths are also generated and evaluated to make a final selection. Any other alternative path will have length longer than the shortest path and may also provide more accessibility to the other unconnected stops. The alternative routes are generated in the following way.

- Nodes untouched by the selected routes in close vicinity of the shortest path are included by meandering along the shortest path.
- Various alternative paths are generated such that the length of an alternative path is not greater than say 1.5 (meander factor) times the shortest distance

between terminals. Further the length should also be within the maximum limits.

- An alternative is considered to be feasible for the further analysis if it provides higher level of demand satisfaction. The demand satisfied per unit length for each of the generated alternatives is estimated. If the demand satisfied per unit length for an alternative is higher than that along the shortest path, the alternative is considered to be feasible for further analysis.
- There is no backtracking along the path

Step III: Evaluation of Alternative paths

The various feasible alternative paths generated between the two terminal hubs are evaluated on the basis of 'Route utilization coefficient' and 'Desire-passenger-km per km' criteria. Figure 3.4 shows an alternative path with 'n' nodes and 'n-1' links. Let i be the intermediate node and L is a link in the path. The alternative paths are analyzed for determining the following parameters.

0————0————0————0————0————0

1   2   L   L+1   n

Figure 3.4: Alternative Path of a Route

$$\text{Flow on link L} = \sum_{L+1}^{n}\sum_{i=1}^{L} Nodal\_demand(i)$$

$$\text{Link Density (L)} = \frac{Flow\ on\ Link(L)}{Length\ of\ Link(L)}$$

$$\text{Average Link Density} = \frac{\sum_{L} Link\ Density(L)}{n-1}$$

$$\text{Max. Link Flow} = \text{Max [Flow on all Links of the path]}$$

$$\text{Demand\_satisfied} = \sum_{i=1}^{n} [Nodal\_demand(i)]$$

$$\text{Demand satisfied per Km.} = \frac{Demand\_satisfied}{Route\,length}$$

$$\text{Route Utilization Coefficient (RUC)} = \frac{\sum_{i=1}^{n-1} flow\ on\ link(L) * length\ of\ link(L)}{Max.\ link\ flow * \sum_{i=1}^{n-1} length\ of\ link\ (L)}$$

$$\text{Passenger\_km} = \sum_{i=1}^{n-1} flow\ on\ link(L) * length\ of\ link(L)$$

$$\text{Passenger\_km per km} = \frac{\sum_{i=1}^{n-1} flow\ on\ link(L) * length\ of\ link(L)}{\sum_{i=1}^{n-1} length\ of\ link\ (L)}$$

$$\text{Desire\_passenger\_km} = \sum_{i=1}^{n} [Nodal\_demand(i)] * \text{shortest distance (i,n)}$$

$$\text{Desire\_passenger\_km per km} = \frac{Desire\_passenger\_km}{Route\,length}$$

Step IV: Selection of Optimal path

The various criteria, which can be used for selection of optimal paths among the generated alternatives, are

Passenger – Km Criteria

The user may select a route with maximum passenger kilometer operated.

If the demand satisfied along two different alternatives is same, then by this criterion longer route will be selected giving a setback to operator's objective.

Average Link Density Criteria

The optimal path selected is one that maximizes the average link density. If the demand of the two alternatives are same then by this criteria shorter route will be preferred. Every link in this criterion is given equal weightage whereas longer link should have been given more weightage.

Standard Deviation of link-density can also be helpful to make a choice. Alternative with minimum value of standard deviation can prove to be a better choice.

Route Utilization Criteria (RUC)

This criterion considers the weightage of different links with reference to their lengths and provides the overall utilization of the path. Alternative with maximum value of route utilization coefficient (RUC) can be selected.

Adopted Criteria of Selection

This study considers combined effect of two criteria – RUC and 'Desire passenger-km per Km'. Alternative paths having route utilization coefficient (RUC) not less than that of the shortest path are firstly short-listed. In this way, the alternatives with low RUC are ignored. From amongst these short listed paths, the one having maximum 'Desire-passenger-km per km' is selected as the optimal route path between the selected terminals.

For the selected optimal path, the total demand satisfied along the path is estimated. Assuming the minimum frequency of operation for the route, the proportion of demand satisfied is identified and the travel demand matrix is updated for further generation of routes. The above-mentioned procedure from step-I to step-IV for generation of inter-hub routes is continued till no further terminal pairs, based on specified criteria, could be identified and significant portion of the total demand is satisfied.

3.2.5 Generation of Secondary Routes

In direction oriented hub and spokes model, secondary routes are to be generated in the influence area of the hubs. These secondary routes may be classified under two categories.

(i) Feeder routes: These are the routes, which originate from the terminal stops within the influence area to the hub terminal.

(ii) Routes connecting the pair of stops, within the influence area of the same hub, having considerable demand and sufficient distance between them.

The input data required for the preparation of routing plan for secondary routes includes the layout of road network, stops in the influence area of the hubs, link distances, link travel times and the intra-hub-travel demand matrix. The model for generating secondary routes consists of the following steps.

(i) Identification of terminals

(ii) Generation of alternative paths

(iii) Evaluation of alternative paths and selection of optimum path

Step-I: Identification of Terminals

Generation of secondary routes within the influence area of hubs requires the identification of two terminals, between which the paths of the secondary routes are to be established. For the feeder routes, one end of the routes to be generated is fixed as hub terminal and the second terminal stop is to be identified. The second type of routes requires both the terminal stops to be identified. Identification of terminals, for both types of routes, is based on the constraints of minimum demand, minimum and maximum distance. Availability of sufficient parking space for terminal stops should also be taken into consideration.

Step II – Generation of Alternative Paths

Shortest distance path is first generated between the identified terminal and the Hub or between the two terminal stops. The area in the vicinity of shortest path is searched to generate the alternative paths subject to following constraints.

- Travel time/ distance of alternative paths is not more than say 1.5 (meander factor) times of the travel time/distance of identified shortest path.
- There is no backtracking in the path.
- Demand satisfied by the alternative is more than that for the shortest path.

Step III- Evaluation of Alternative Paths and Selection of Optimal Path

Following statistics are then estimated for each of the alternative paths.

- Demand satisfied along the route
- Demand satisfied per km
- Pass - km along the route
- Desired-Pass - km per km

An alternative that maximizes the desired-pass-km/km is taken as the optimal path. The procedure from step 1-3 is repeated till all stops in the influence area are considered and optimally generated routes within the influence area for a particular hub are obtained.

3.2.6 Scheduling Model for Inter-hub Routes

Scheduling can be defined in the following general terms: Given the origin destination matrix for the bus trips of design period, the underlying bus network characterized by the overlapping routes, how optimally to allocate the buses among these routes? It is assumed that the origin destination matrix for the bus trips is not affected by the allocation of buses. Despite the fact that origin destination flows being given and assumed fixed, the number of passengers using each path will still be a function of the bus allocation because of the frequency share on overlapping links.

In a metropolitan city, the total hours of operation for public transportation system vary due to traveler's behavior and demand. The demand varies during the different periods of the day. Accordingly, the operational period of public transport is converted into equivalent peak hours by assigning weightage to different hours of the day.

The number of bus trips to be operated for a route depends upon the demand served along the route and the passenger flow on various links of the route. The demand served along

the route can give only little idea about the desired bus trips, as some inter-nodal demand may be shared by more than one route. The passenger flow on the link of a route helps to determine the bus trips needed on a route, as the link may have a number of overlapping routes passing over it.

3.2.6.1 Estimation of Optimal Bus Trips

To estimate the optimal bus trips for a route, an iterative heuristic algorithm as illustrated in Figure 3.5 is adopted in the scheduling model, the steps of which are enumerated below:

(i) Estimation of passenger flow on each link
(ii) Determination of desired trips for each link
(iii) Assignment of minimum trips for each route
(iv) Estimation of additional trips on each route
(v) Revised trips on each route of transit network

Step-I: Estimation of passenger flow on each link

A hub and spokes bus transit network consists of a large number of inter-hub routes overlapping each other on a number of links. For each origin and destination node pair(i,j) of the transit network, the passenger flow on each link is estimated. The shortest path on the route network for each node pair(i,j) is taken into consideration and the total demand matrix is loaded on the transit network. The passenger flow on each link of the network is estimated as

$$\text{Passenger\_link\_flow(L)} = \sum_j \sum_i \text{int\_}stop\_dem(i,j) \;;$$

if shortest path from i to j passes over link L.

Step II: Determination of desired bus trips for each Link

Desired trips for each link of the transit is determined on the basis of passenger-link-flow on each link and the desired average bus load for a specified level of service. The criteria as given in Table 3.1 for different levels of service may be taken up in this work.

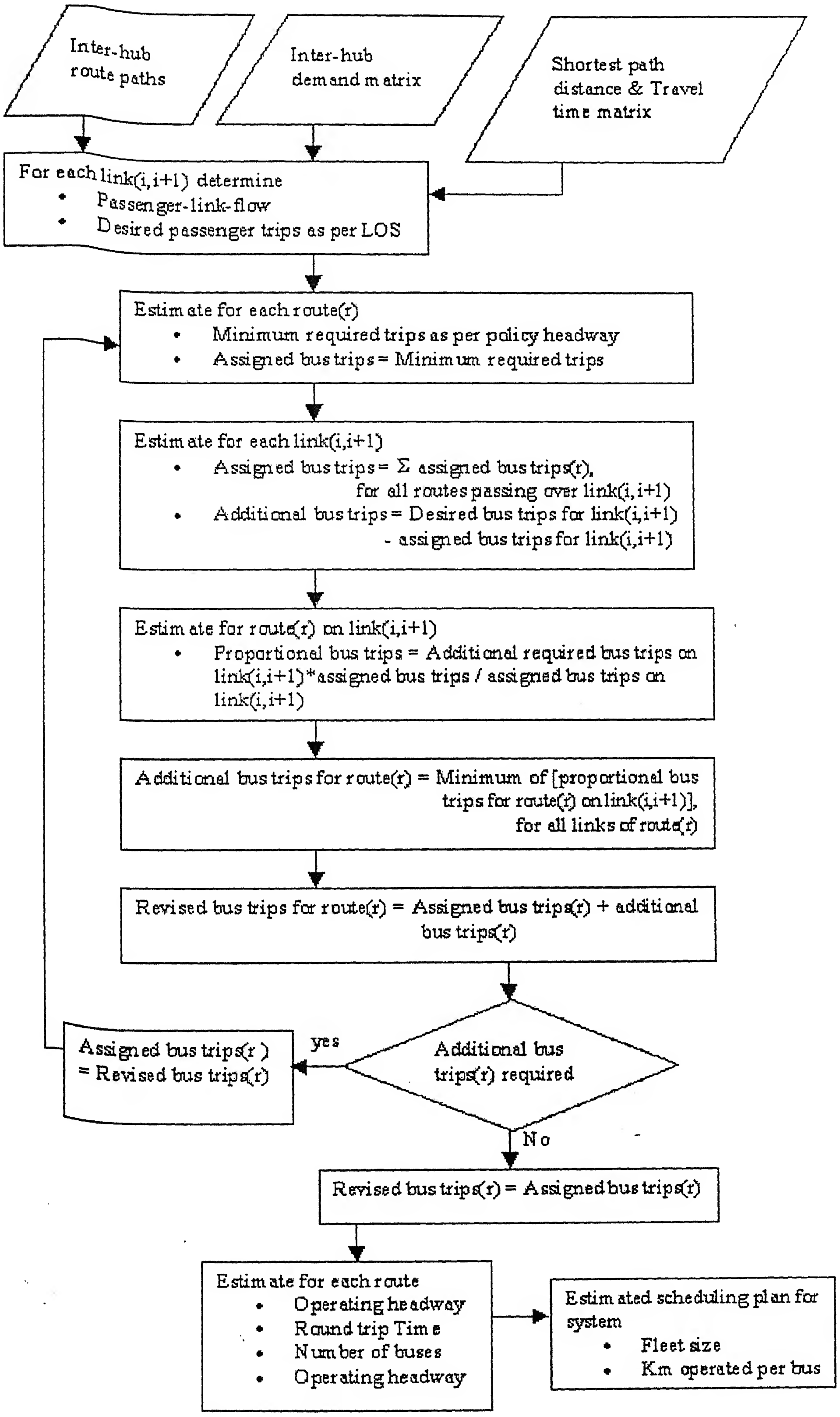


Figure 3.5: Scheduling Model for Inter-hub Routes

Table 3.1: Desired Bus Loads for different Level of Services

LEVEL OF SERVICE	DESIRED AVERAGE BUS LOAD
LOS-I	35
LOS –II	40
LOS-III	45
LOS-IV	50

$$\text{Desired bus trips on link(L)} = \frac{Passenger\_link\_flow(L)}{Desired\_average\_bus\_load(LOS)}$$

where, LOS defines the specified level of service.

Step-III: Assignment of minimum trips for each route

In a city area, the total hours of operation for public transportation system vary due to trip maker's behavior and demand. The demand varies during the different hours of the day. Accordingly, the operational period of public transport is converted into equivalent peak hours by assigning weightage to different hours of the day. The minimum trips, which are required to each route is estimated by considering the weighted equivalent peak hours for the day and policy headway.

$$\text{Minimum required trips on route(r)} = \frac{Weighted\_equivalent\_peak\_hours}{policy\_headway}$$

In the first iteration, each route is assigned these trips

$$\text{Assigned bus trips}\,(\,\mathrm{r}\,) = \text{Minimum required trips on route}\,(\,\mathrm{r}\,)$$

Step-IV: Estimation of additional trips on each route

A large bus transit network will have routes overlapping over a number of links in the network. To account for overlapping in estimating the trips on each route of the network, Figure 3.6 shows three routes r1, r2 and r3 of a transit network overlapping over a link(i,i+1).

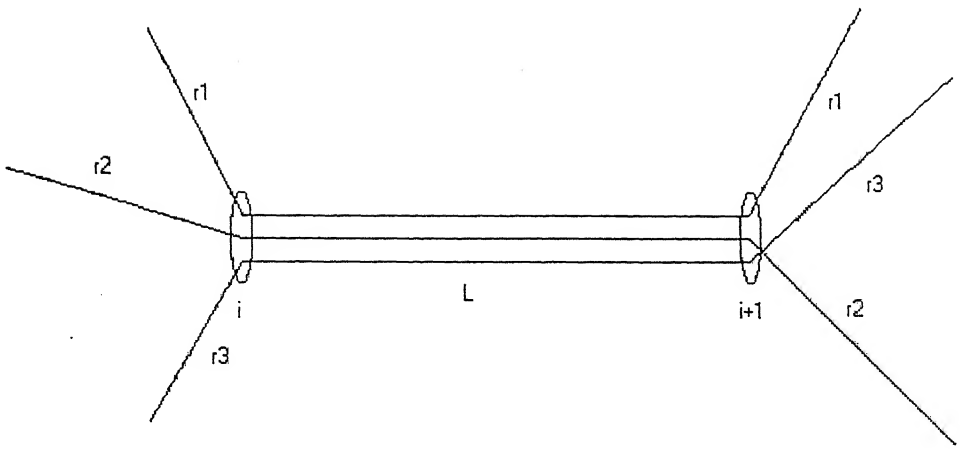


Figure 3.6: Overlapping Routes over a Link

The total assigned bus trips contributed by each of the route moving on the link(i,i+1) is determined as:

Assigned bus trips on link(i,i+1) = $\sum$ Assigned bus trips(r);

for all routes passing over link(i,i+1).

The difference between the desired bus trips for link(i,i+1) as estimated in step-II and the already assigned bus trips on link(i,i+1) gives the additional required bus trips on link(i,i+1).

Additional required bus trips on link(i,i+1) =

Desired bus trips for link(i,i+1) - Assigned bus trips for link(i,i+1).

These additional required bus trips on link(i,i+1) are to be proportioned among the overlapping routes passing on the link(i,i+1). These proportional bus trips for route 'r' on link 'L' can be estimated as:

Proportional bus trips(r,L) =

$$\frac{Additional\,required\,bus\,trips\,on\,link(i,i+1) * Assigned\,bus\,trips(r)}{Assigned\,bus\,trips\,on\,links(i,i+1)}$$

The estimated proportional bus trips on a route are determined for each link of the route path. The minimum of these trips is considered as the additional trips for the route.

Additional bus trips(r) = Minimum of [Proportional bus trips(r,L)],
for all links of route r.

Step-V: Revised trips on each route of transit network

The revised bus trips for each of the overlapping routes moving on the link are determined as the sum of already assigned trips and the additional bus trips for the route.

Revised bus trips(r) = assigned bus trips(r) + additional bus trips(r)

The determination of revised bus trips for a route 'r' completes one iteration of the model. In the next iteration, these revised bus trips act as the already assigned bus trips

Assigned bus trips (r) = Revised bus trips (r)

and the process of step IV is repeated. Additional bus trips are again determined for all the routes. This iterative process is continued till no more additional bus trips are required on each route.

3.2.6.2 Estimation of Round Trip Time

The round trip time for a route consists of travel time in each direction, total halt time at the stops, and the layover time at the terminals. The travel time is estimated, considering the vehicle operating speeds on different links of the route. A layover time is provided at both the hubs based on route characteristics and operating policies. The total round trip time for the route is determined as follows

Round_Trip_Time (r) = 2 (Travel Time (r) + Halt time + Lay over time)

3.2.6.3 Estimation of Buses for Operation

The scheduling plans are to be prepared both for peak and off peak periods. Given the share of demand during a certain period, the operating bus trips for the period are determined and the operating headway is estimated.

$$\text{Operating\_headway}(r) = \frac{\textit{Time period for Scheduling}}{\textit{Desired Bus Trips}(r)}$$

Knowing the operating headway and the number of the bus trips, the number of buses required for the desired scheme of operation is determined.

$$\text{Number of Buses (r)} = \frac{Round\,Trip\,Time(r)}{Operating\,headway(r)}$$

The number of parking lots at the terminals for the route under consideration is estimated as

$$\text{Number of Parking Lots (r)} = \frac{Lay\,over\,Time(r)}{Operating\,headway(r)} + 1$$

3.2.6.4 Estimation of System Characteristics

Following characteristics of the scheduling policy are also estimated for the analysis of the system.

Average Waiting Time – The average waiting time of passengers on a route is taken as the half of the headway of operation

Average Waiting Time (r) = 0.5 * Operating headway (r)

Total Km. Operated (r) = 2 * Length of the route (r) * Operating Trips (r)

$$\text{Km Operated per Bus (r)} = \frac{Total\,Km\;operated(r)}{Number\,of\;Buses(r)}$$

$$\text{Fleet size} = \sum_r Number\,of\;buses(r)$$

$$\text{Average Km. Operated per bus for the system} = \frac{\sum_r Total\,Km\,operated(r)}{\sum_r Number\,of\;buses(r)}$$

Average waiting time for the system

$$= \frac{\sum_r 0.5 * operating\,headway(r) * Total\;demand(r)}{\sum_r Total\;demand(r)}$$

$$\text{Total operating distance} = \sum_{r} Total\ km\ operated(r)$$

$$\text{Km operated per bus for the system} = \frac{Total\ operating\ distance}{Fleet\ Size}$$

3.2.7 Scheduling for Secondary routes

Secondary routes are generated within the influence area of each hub and their primary aim is to feed the hub terminals. A generated feeder path of secondary routes has one terminating end as the Hub and the other is the bus terminal. As a feeder route moves from stop terminal to Hub, the passenger flow on the links increases, as persons will be boarding to reach Hub terminal. Opposite will be the case, when movement is from Hub terminal to stop terminal. Link closest to the hub terminal will have the maximum passengers flow and one touching the bus terminal will have the minimum flow.

The number of bus trips on a feeder route of secondary route primarily depends on the maximum link flow. But there may be considerable variation of the passenger flows on the various links along the route. The design of services on max flow would leave the bus underutilized on initial links and optimally utilized only for few links close to the hub. If the planning is done on the basis of minimum load then bus is over crowded on the last few links. Therefore, weighted average link flow is taken into consideration in determining the bus trips.

Four different levels of service for peak-period and mid day period are specified in the scheduling model for determining the bus trips. The bus trips obtained from the maximum link flow and weighted link flow are compared and optimal value of bus trips are assigned to the secondary routes. The round trip time for a route is estimated and the required headway subject to the minimum and maximum constraints of headway for operation of buses is estimated. The trips operated in each direction are calculated and the total fleet size for peak period and off-peak period at different levels of services is estimated. The operational characteristics are obtained for all the secondary routes and finally the characteristics of the system are estimated.

3.3 PROGRAM SYSTEM

The developed methodology for planning of bus transit system can be adopted for a large network of a metropolitan city. The methodology includes a number of heuristic and optimization models to determine the optimal number of hubs, estimate the inter-hub and intra-hub travel demand, routing and scheduling of inter-hub routes and secondary routes. All these models are interlinked and the integration of these models is adopted by development of a program system as shown in Figure 3.7. A brief description of the modules is presented below.

- INPUT

This module is meant for keeping all the input files that are required for the execution of the model.

- FIRST

This module prepares for model execution and arranges the data given in input files in sequential form.

- DATA

This is meant for keeping all the data files obtained from the module FIRST.

- NETWORK

Under this module, the existing road network is prepared. The Cartesian X and Y coordinates of the nodes in the network are required for the network display on the screen. This module facilitates displaying the network in parts and zooming around a node.

- SH_DIST

This module generates the shortest inter bus stop distance matrix through road network.

- SH_TIME

This module generates the shortest inter stop shortest time matrix through road network.

- BUS_SOM

This module groups the total number of bus stops in the predetermined clusters using Self-organizing map approach.

- BUS_FUZ

This module partitions the total number of bus stops in the predetermined clusters through Fuzzy-C-means clustering approach.

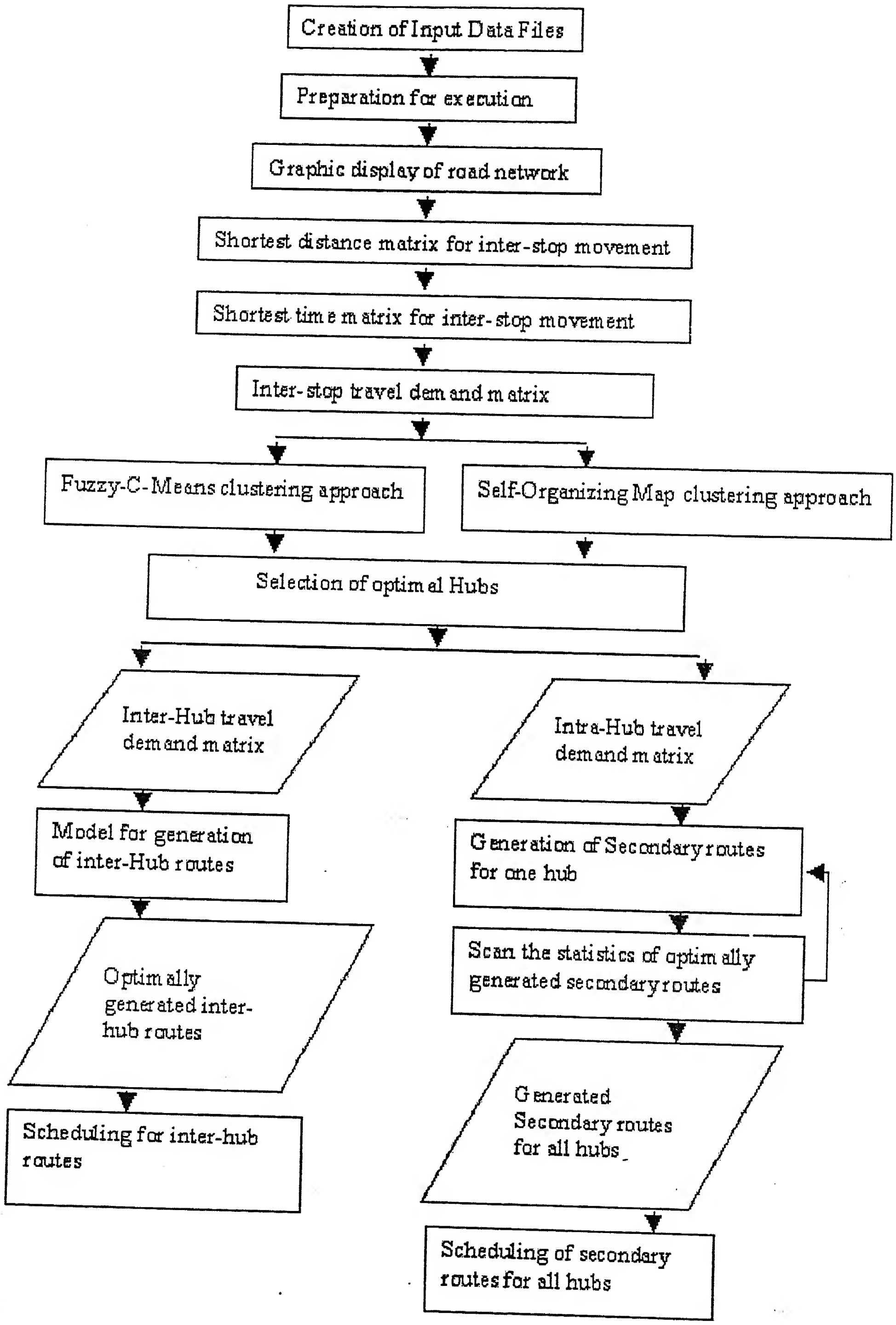


Figure 3.7: Interconnection of different Modules in Bus Transit System

- DEMAND

This module determines the inter-hub and intra-hub demand matrix for Bus transit system.

- PRE_HUB

In this module the files for generation of inter-hub routes are prepared.

- HUB_ROUT

Inter-hub routes are generated in this module and statistics of the inter-hub routes are estimated.

- PRE_SPK

This module prepares the files for generation of secondary routes.

- SPK_ROUT

In this module the secondary routes within the influence area of each hub are generated.

- SCH_HUB

Scheduling of inter-hub routes for peak period and off-peak period at various levels of service is facilitated in this module.

- SCH_SPK

Scheduling of inter-hub routes for peak period and off-peak period at various levels of service is done in this module.

3.4 SUMMARY

In this chapter, methodology adopted to solve the bus transit network design problem for large cities has been presented. The methodology involves hub and spokes approach, where optimal selection of hubs is attempted through a mathematical model and the objective is to minimize the 'Total Passenger Time' for the bus transit system. A three-step procedure is adopted to locate the optimal hubs for the bus transit system. Two types of routes, inter-hub routes and intra-hub routes for all hubs are generated. For this purpose, the inter-stop demand matrix is adjusted to estimate the inter-hub demand matrix and intra-hub demand matrix. An iterative heuristic scheduling model to estimate the optimal bus trips for an inter-hub route is discussed. The heuristic scheduling model for secondary routes is presented. The chapter concludes with the interconnection of different modules developed for the bus transit network.

CHAPTER – 4

DECISION SUPPORT SYSTEM OF FEEDER BUS ROUTES FOR RAPID TRANSIT SYSTEM

4.1 INTRODUCTION

Feeder bus services to high capacity transit system play an important role in ensuring an integrated multi modal public transport operation. With the implementation of a new Mass Rapid Transit System (MRTS) in a metropolitan city, the existing bus transit network undergoes a gradual change. Till the time the MRTS network is not fully implemented, the existing bus system has to play both the role of feeder as well as the main mode of public transport depending upon the influence area of MRTS and its schedule of implementation. This dual role would entail restructuring of existing bus routes falling in the influence area of MRTS alignment. To ensure that both MRTS and Bus systems act complement to each other, some of the existing bus routes would get deleted and some would get curtailed or extended. Thus, systematic, scientific and optimal planning of feeder bus services and restructuring of existing bus transit network assumes great importance.

This chapter presents a Decision Support System (DSS) developed to prepare optimal routing and scheduling plan of feeder bus routes for a Mass Rapid Transit System (MRTS) and to restructure the existing bus route network. This interactive Decision Support System has a series of Heuristic optimization models integrated with

Geographical Information System (GIS) environment, is user friendly and is capable of handling large network.

4.2 OBJECTIVES AND SCOPE OF WORK

The objective is to optimally plan the feeder bus system for an MRTS network in a metropolitan city. The scope of the work is confined to:

i. Estimate the travel demand matrix for the new MRTS based on the mode choice analysis for MRTS and existing bus network
ii. Generate feeder bus routes as per the estimated travel demand matrix for MRTS and expected station loads.
iii. Prepare scheduling plan of feeder bus routes, consisting of different types of vehicles, to meet the expected feeder trip demand at various levels of service
iv. Study the possible impact on existing bus routes, which are operating within the influence area of MRTS stations, and to restructure these routes.

4.3 STUDY METHODOLOGY

Based on the defined objective and scope of work, broad study methodology is shown in Figure 4.1. It has the following important stages.

- Study of existing road network, existing bus transit system and proposed MRTS network.
- Mode-choice analysis to estimate the passenger demand matrix for combined MRTS and feeder network.
- Models for delineation of Influence Area for each MRTS station of the network
- Planning of feeder bus route network for the proposed MRTS network.
- Preparation of scheduling plan for the generated feeder bus system.
- Approach to restructure the existing bus route network in the light of MRTS and feeder bus routes.

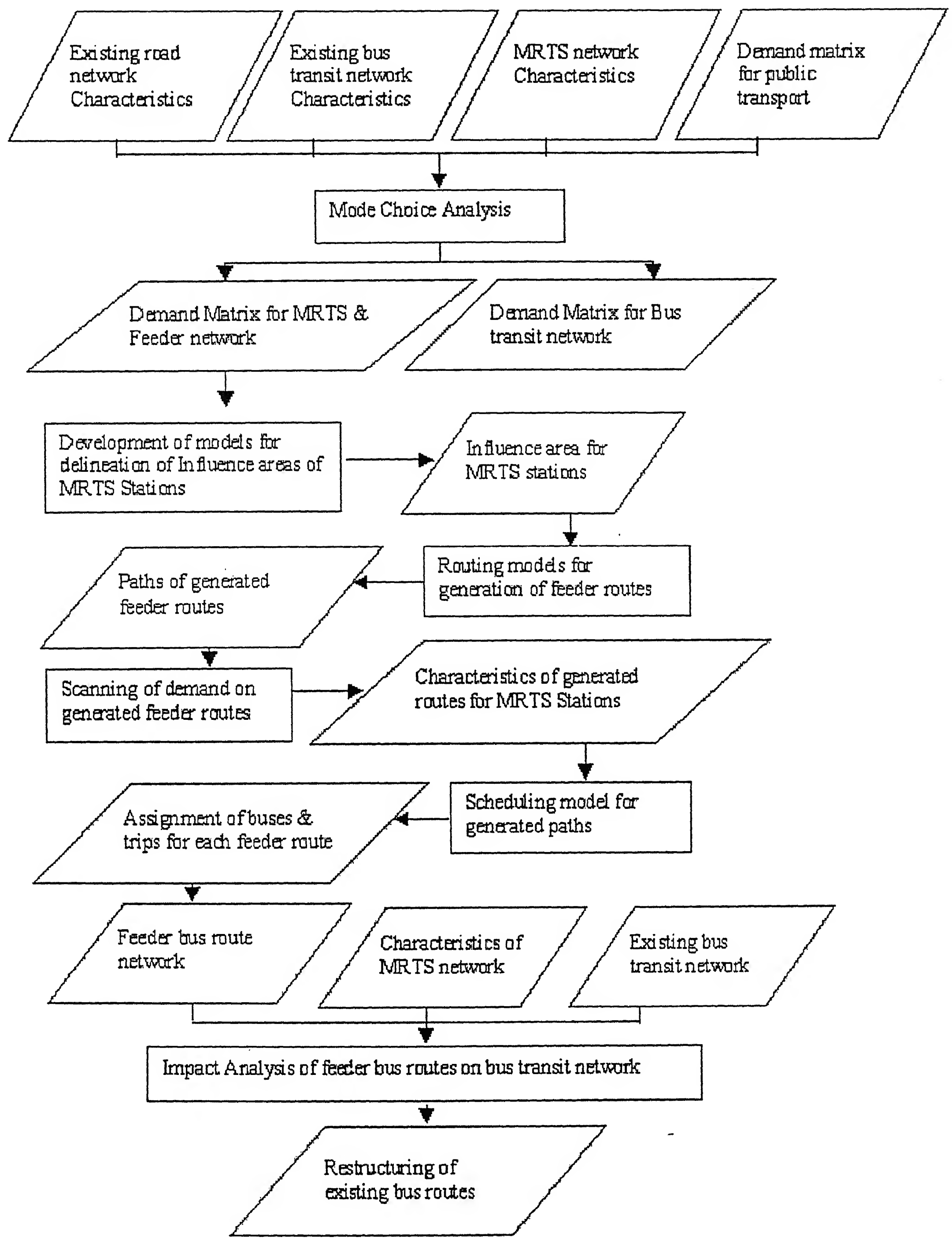


Figure 4.1: Broad Study Methodology for Feeder Bus System

4.3.1 Generation of Data Base

Generation of comprehensive database, representing various subsystems, is highly important for successful implementation of the study methodology. Data are needed for the existing conditions and at the time when MRTS corridors are introduced in the metropolitan city for which feeder services are being planned. The data required for the study relate to:

4.3.1.1 Inventory of Road Network Characteristics

A complete inventory of existing road network involves the nodes (both bus stops and intersection) and links connecting these nodes. The various characteristics of interest for the different links of the road network are:

- Layout of road network with stops and intersections
- Link length
- Link speed
- Characteristics of link movement - One-way or two-way road links
- Type of buses, Standard buses or Mini buses, which can ply on a link.

4.3.1.2 Inventory of Existing Bus Routes Characteristics

The city may have a number of existing bus routes to serve the trip makers. The characteristics, which may be of interest for planning the feeder bus transit system include:

- Path of existing bus routes with terminals and intermediate nodes.
- Scheduling plan of existing bus routes during different time periods

4.3.1.3 Inventory of MRTS Network Characteristics

The MRTS network consists of a number of stations and the links connecting these stations. The important characteristics of MRTS required for planning the feeder services for the MRTS are:

- Layout of MRTS network of stations and links.
- Link length
- Link speed

4.3.1.4 Travel Demand Matrix for Inter-Stop Movement

Planning of feeder services require data at the disaggregate level (i.e. at bus stop level) to represent the true picture. This daily demand matrix and its distribution over different periods can be generated from the primary surveys to be conducted at the bus stops. However conducting of primary surveys at level of bus stops in a large city will require lot of resources and may not be possible. For transportation planning, the city is divided into a number of traffic zones and demand matrix at zonal level is generally available. This zonal demand matrix, supplemented with trip generation information of bus stops, may be used to generate the desired inter stop travel demand matrix.

Bus stops lying in a traffic zone are identified and relative weights are assigned to each stop. These weights are based on the traffic generation potential of a bus stop in the total trip generation of the zone. These weights could be different for production and attraction. When a zonal boundary is along a road, a bus stop may be considered to lie in more than one traffic zone and it may have separate weights for each zone. Knowing the inter zonal travel demand matrix, the inter stop demand matrix for the design year is derived on the following basis.

Let a traffic zone (zt_1) has q stops (i_1, i_2, i_3 .. i_q) and zone (zt_2) has s bus stops ($j_1, j_2, j_3, \ldots j_s$). The inter zonal demand (zt_1, zt_2) will be split to (X x Y) parts, each part giving an inter stop demand.

$$\text{Int\_stop\_dem}(i_x, j_y) = \text{Int\_zon\_dem}(zt_1, zt_2) * \text{PD}_{\text{factor}} * \text{AT}_{\text{factor}}$$

where Int_stop_dem(i_x, j_y) is the estimated inter stop demand between i_x and j_y with stops i_x and j_y lying in zones zt_1 and zt_2 respectively; and Int_zon_dem(zt_1, zt_2) is the inter zonal demand between traffic zones zt_1 and zt_2.

$$\text{PD}_{\text{factor}} = \frac{WP(i_x)}{WP(i_1) + WP(i_2) + WP(i_3) + \ldots\ldots WP(i_q)}$$

$$\text{AT}_{\text{factor}} = \frac{WA(j_y)}{WA(j_1) + WA(j_2) + WA(j_3) + \ldots\ldots WA(j_s)}$$

where $WP(i_x)$ is production weight of bus stop i_x and $WA(j_y)$ is the attraction weight of j_y bus stop.

4.3.2 Mode Choice Analysis

In a metropolitan city, the existing modes of public transportation, before the introduction of MRTS, are generally in different forms of buses and intermediate public transport (IPT). With the introduction of a new public transport mode, some share of trip makers will shift from the existing bus system to the new public transport mode. Similarly, some portion of demand from private modes may also shift to the new system. However the major component of the demand coming to MRTS will be one transferred from the existing bus transit system. To predict the demand on MRTS, a mode-choice analysis is called for. Generally the mode-choice behavior of trip-makers can be explained by three categories of factors.

(i) Characteristics of the available modes

(ii) Socioeconomic status of the trip maker

(iii) Characteristics of the trip

Logit model from the family of mode choice models has been considered to split the travel demand between the existing bus transit system and the newly introduced MRTS. This trip-interchange mode usage model is appropriate for any size urban area with any level of transit usage. It is most appropriate in larger urbanized areas with an appreciable level of transit usage. The term logit refers to the S-shaped curve that divides the commuters between various modes depending on each mode's relative desirability for any given trip. Modes are said to be relatively more desirable if they are faster, cheaper, or have other more favorable features than competitive modes. The better a mode is, the more utility it has for the potential traveler. A utility function measures the degree of satisfaction that people derive from their choices. A disutility function represents the generalized cost that is associated with each choice. The magnitude of either depends on the characteristics or attributes of each choice and on the characteristics or socioeconomic status of the individual making a choice. The characteristics of the trip like trip purpose also bear a relationship to the utility associated with choosing a particular mode of travel. In order to specify a utility function, it is necessary to select the relevant parameters and to select the particular functional form relating the selected variables. The utility (or

disutility) function is typically expressed as the linear weighted sum of the independent variables or their transformation.

For sharing the inter stop travel demand between MRTS and Bus transit network, utility measure of the two public transport modes is to be calculated. Measure of utility, a function of travel time, travel cost, comfort, transfer penalty etc., may be expressed as:

$$UC_{Bus} = a_0 + a_1 * T\_Time_{Bus} + a_2 * T\_Cost_{Bus} + a_3 * C\_fort_{Bus} + a_4 * Trans\_Plt_{Bus}$$

$$UC_{MRTS} = b_0 + b_1 * T\_Time_{MRTS} + b_2 * T\_Cost_{MRTS} + b_3 * C\_fort_{MRTS} + b_4 * Trans\_Plt_{MRTS}$$

where

UC_{Bus} is utility measure of bus transit network

UC_{MRTS} is utility measure of MRTS

a_0, a_1, a_2, a_3, a_4 are utility coefficients of bus transit network

b_0, b_1, b_2, b_3, b_4 are utility coefficients of MRTS

T_Time_{Bus} is travel time of bus transit network

T_Time_{MRTS} is travel time of MRTS

T_cost_{Bus} is travel cost of bus transit network

T_cost_{MRTS} is travel cost of MRTS

C_fort_{Bus} is comfort level of bus transit network

C_fort_{MRTS} is comfort level of MRTS

$Trans\_plt_{Bus}$ is transfer penalty of bus transit network

$Trans\_plt_{MRTS}$ is transfer penalty of MRTS

The parameters of travel time and travel cost for MRTS systems would also include travel time and travel cost of feeder system. The data can be used to calibrate the coefficients of the parameters. Once these utility measures are calculated then proportion of demand on each mode is calculated using Logit model.

$$P_{Bus} = \frac{e^{-UC_{bus}}}{e^{-UC_{bus}} + e^{-UC_{MRTS}}}$$

$$P_{MRTS} = \frac{e^{-UC_{MRTS}}}{e^{-UC_{bus}} + e^{-UC_{MRTS}}}$$

where,

UC_{Bus}, UC_{MRTS} are utility measures of the bus transit system and MRTS.

P_{Bus}, P_{MRTS} are the proportion of demand of the bus transit system and MRTS respectively.

The utility measures of bus transit system and MRTS include the parameters of travel time, travel cost and transfer penalty, which need to be determined before they are put into the utility functions of the two modes. If the MRTS system does not exist at present and is to be introduced, whereas, the bus system in the study area already exists and the routes are operating, then one has to calibrate the values of the various parameters with respect to MRTS. The mode choice analysis determines the proportion of demand between the two modes for each origin and destination node pair, it is therefore, desirable to calculate the travel time and travel cost for each node pair for both the public transport modes.

4.3.2.1 Estimation of Inter-stop Travel Time by Existing Bus Routes

A metropolitan city has a large network of bus stops and bus links. The existing bus transit system in the city may have a large number of bus routes serving the stops. A trip maker may able to perform a trip between an origin and destination either through a directly connected route or by a series of bus routes with some transfers. As it may not be feasible to provide direct bus routes between each O-D pair, normally up to two transfers are considered while planning for bus routes. For determining the travel time between any node pair (i,j) on an existing bus route network, the following approach is adopted in the model.

4.3.2.1.1 Travel Time Estimation by No Transfer Cases

When a node pair is directly connected through a bus route, then it is defined as the movement by zero transfer routes. A node pair may have a number of directly connected routes passing through them. The travel time by the shortest of all directly connected routes is considered for further analysis. Figure 4.2 shows three direct routes RI, RII and RIII connecting an O-D pair of 'i' and 'j'. The travel time between the node pair is the minimum of travel times by the alternative routes. Matrix of travel time for all directly connected inter stop movements is calculated and used for further analysis. Travel time includes both in vehicle time and wait time. For preliminary analysis, the average wait time on a route is taken as half of the route headway.

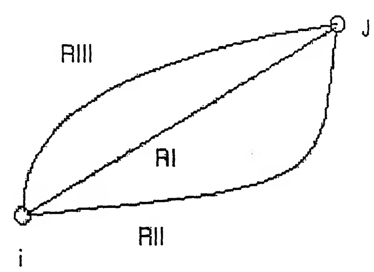


Figure 4.2: Inter-stop Routes with Zero Transfer

Travel time on route Ri = In_Vehicle _Time(Ri) + 0.5 (headway(Ri))
Shortest Travel_Time (i,j) = Min[(Travel times on routes RI, RII, RIII)]

4.3.2.1.2 Travel Time Estimation for One-Transfer Cases

If a node pair is not directly connected then the model searches for one-transfer points. For this all routes passing from origin node 'i' and all routes passing from destination node 'j' are searched and if there is any common point between them then that is considered as a transfer point. Figure 4.3 shows the transfer points T1, T2, T3, T4 and T5 obtained for traveling from node 'i' to node 'j'. The shortest distance transfer point is searched and travel time is calculated. Thus for every OD pair, shortest travel time with one transfer routes is calculated and shortest travel time matrix with one transfer routes is

calculated. The OD pairs, which are unconnected by either zero transfer or one transfer routes are also earmarked.

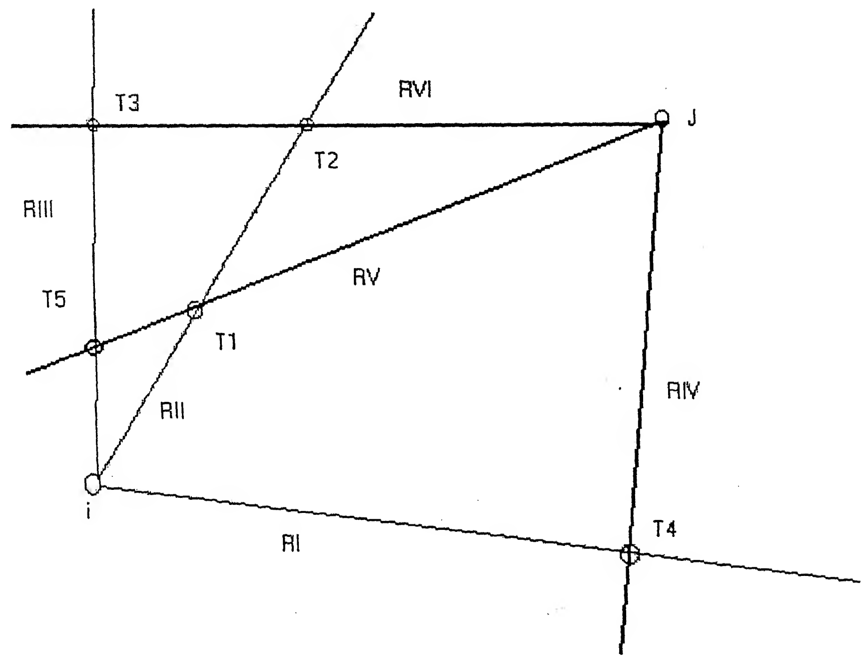


Figure 4.3: Transfer Points for One-Transfer Routes

T_T1=T_Time(i,T1)+0.5(headway(RII))+T_Time(T1,j)+0.5(headway(RV))
+Transfer_time(T1)

T_T2=T_Time(i,T2)+0.5(headway(RII))+T_Time(T2,j)+0.5(headway(RVI))
+Transfer_time(T2)

T_T3=T_Time(i,T3)+0.5(headway(RIII))+T_Time(T3,j)+0.5(headway(RVI))
+Transfer_time(T3)

T_T4=T_Time(i,T4)+0.5(headway(RI))+T_Time(T4,j)+0.5(headway(RIV))
+Transfer_time(T4)

T_T5=T_Time(i,T5)+0.5(headway(RIII))+T_Time(T5,j)+0.5(headway(RV))
+Transfer_time(T5)

where T_T1, T_T2, T_T3, and T_T4,T_T5 are the total travel times through transfer points T1, T2, T3,T4 and T5 respectively.

T_Time(s,k) is the travel time between the two nodes.

Transfer time at a stop corresponds to the locations of bus halts for different directions.

The shortest travel time for the node pair (i,j) is the minimum of all the five alternatives in the above case

Shortest Travel_Time(i,j) = Min[T_T1,T_T2,T_T3,T_T4,T_T5]

4.3.2.1.3 Travel Time Estimation for Two-Transfer Cases

If a node pair is not connected either directly or by one transfer route then the model searches for two-transfer points. For every origin node 'i', a set of routes is passing through it and on each route of this first leg, there are a number of nodes. Similarly, a set of routes passes through destination node 'j', and a number of nodes lie on each of these routes on the second leg of search process. Routes passing through node 'i' is searched for that node, which is having a route passing through it, as well as passing through a node, which lies on the second leg of routes through 'j'. These transfer nodes are shown in Figure 4.4 as T1 and T2 or T3 and T4. All such combinations are searched and the combination, corresponding to the 'minimum travel time' gives the shortest travel time between the O-D pairs.

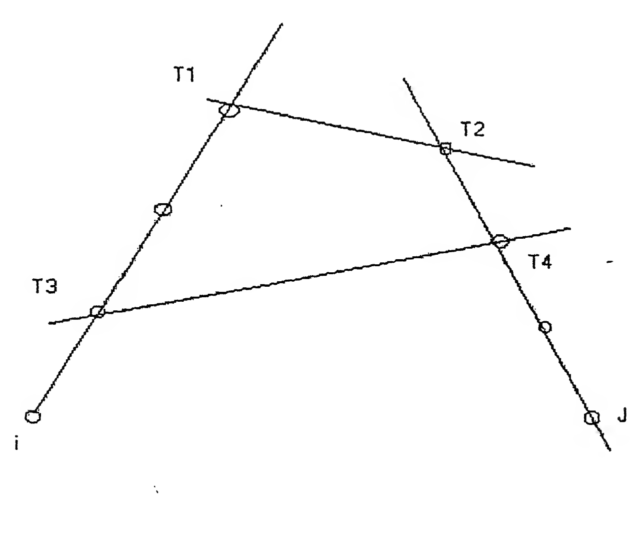


Figure 4.4: Transfer Nodes for Two Transfer Routes

T_X1= Shortest Travel Time(i,T1) + Shortest Travel Time(T1,T2) +
Shortest Travel Time(T2,j) + Transfer Time(T1) + Transfer Time (T2)

T_X2= Shortest Travel Time(i,T3) + Shortest Travel Time(T3,T4) +
Shortest Travel Time(T4,j) + Transfer Time(T3) + Transfer Time (T4)

Shortest Travel_Time(i,j) = Min[T_X1,T_X2]

If an OD pair is not connected with up to two transfers, then the pair is said to be unconnected by existing bus routes and a very high figure may be displayed under the number of transfers involved in connecting an OD pair.

Following matrices are computed in the process to obtain the travel time by existing bus routes.

- *Shortest inter stop distance matrices {sh_road dist(i,j)}:* These matrices are computed through available bus routes, if there is a connection of stop i and j by zero, one or two transfer routes .
- *Shortest inter stop travel time matrices {sh_road travel time (i,j)}:* These matrices are computed through available bus routes, if there is a connection of stop i and j by zero, one or two transfer routes. The 1/2 of headway of the route connecting the OD pair would be taken as waiting time and included in the travel time of the passengers traveling on the route.

4.3.2.2 Estimation of Inter-Stop Travel Time through MRTS

When the MRTS is newly introduced, the trip makers may not be able to clearly judge the nearest possible MRTS stations in the vicinity of their origin or destination. The approach to determine the best path through MRTS follows in the following steps.

(i) For each stop, determine five closely located MRTS stations, those with shortest distance from the stop.

(ii) For a bus stop pair (i,j), let there be MRTS stations (mt_1, mt_2, mt_3, mt_4, mt_5) in vicinity of stop i and let there be MRTS stations (nt_1, nt_2, nt_3, nt_4, nt_5) in vicinity of stop j.

(iii) To travel through the combination of MRTS and road between stop i and j, a total of 25 alternative paths are now available. Total travel times are estimated for each of the 25 alternatives and one with least time is selected.

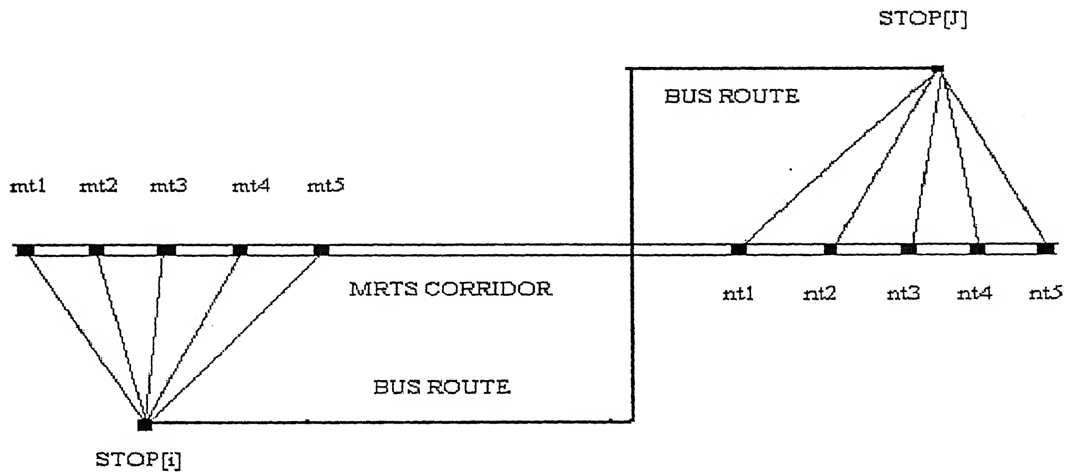


Figure 4.5: Estimation of Inter-stop Travel Time

Total travel time through mt_1,nt_1 = TT_road(i,mt_1)+ TT_MRTS(mt_1,nt_1) + TT_road (nt_1,j) + transfer time at station mt_1 + transfer time at station nt_1

TT_road(i,mt_1): travel time along the road from stop i to MRTS station mt_1

TT_road(j,nt_1): travel time along the road from stop j to MRTS station nt_1

TT_MRTS(mt_1,nt_1): travel time along MRTS between stations mt_1 and nt_1.

Minimum of the 'Total Travel Time' for 25 alternative paths establishes the best path to travel through MRTS.

Accessibility of the various inter-node transfer with respect to the MRTS are determined through two incidence matrices [con_mrts (i,j)] and [sec_mrts(i,j)]. If inter-nodal transfer between 'i' and 'j' use MRTS system then [con_mrts (i,j)] depicts the connectivity between the node 'i' and MRTS station and [sec_mrts(i,j)] gives the connectivity between the second MRTS station and node 'j'.

The following matrices are also computed while calculating the travel time through MRTS.

- Shortest inter MRTS station distance matrix { sh_MRTS dist(mt,nt)}
- Shortest inter MRTS station travel time matrix { sh_MRTS travel time(mt,nt)}, half the headway of MRTS connecting the OD pair would be taken as waiting time and included in travel time of the passengers traveling on the MRTS corridor joining the stations on the route.
- Shortest inter stop- MRTS station distance matrix for all bus stops and MRTS stations { sh_stop MRTS dist(i,mt)}
- Shortest inter stop- MRTS station travel time matrix for all bus stops and MRTS stations {sh_stop MRTS travel time (i,mt)

4.3.2.3 Estimation of Travel Cost

The trip makers while traveling through bus system or MRTS has to pay some monetary value for the journey. The travel cost in case of buses is generally in the form of unit rate per kilometer or slab system. In case of MRTS system, the passengers may travel through a combination of two modes, one is through feeder bus system and the other is by metro. For the feeder bus system the cost of travel may be in the form of unit rate or slab system as in the case of bus system. Similarly the travel cost between the MRTS stations can be taken up on unit rate basis or slab system. Combination of slab system on one mode and unit rate on other is another possibility. Inter-stop unified fare matrix for both MRTS and feeder bus system can also be taken into consideration for the estimation of travel cost.

4.3.2.4 Application of Mode Choice Analysis Model

Mode choice analysis model as shown in Figure 4.6 is evolved to assess the number of commuters who may shift from the existing bus system to MRTS – feeder bus combination based on the parameters of travel time, travel cost and modal characteristics of the two modes and can be applied in a metropolitan city. A commuter may opt to travel through MRTS subject to the following conditions.

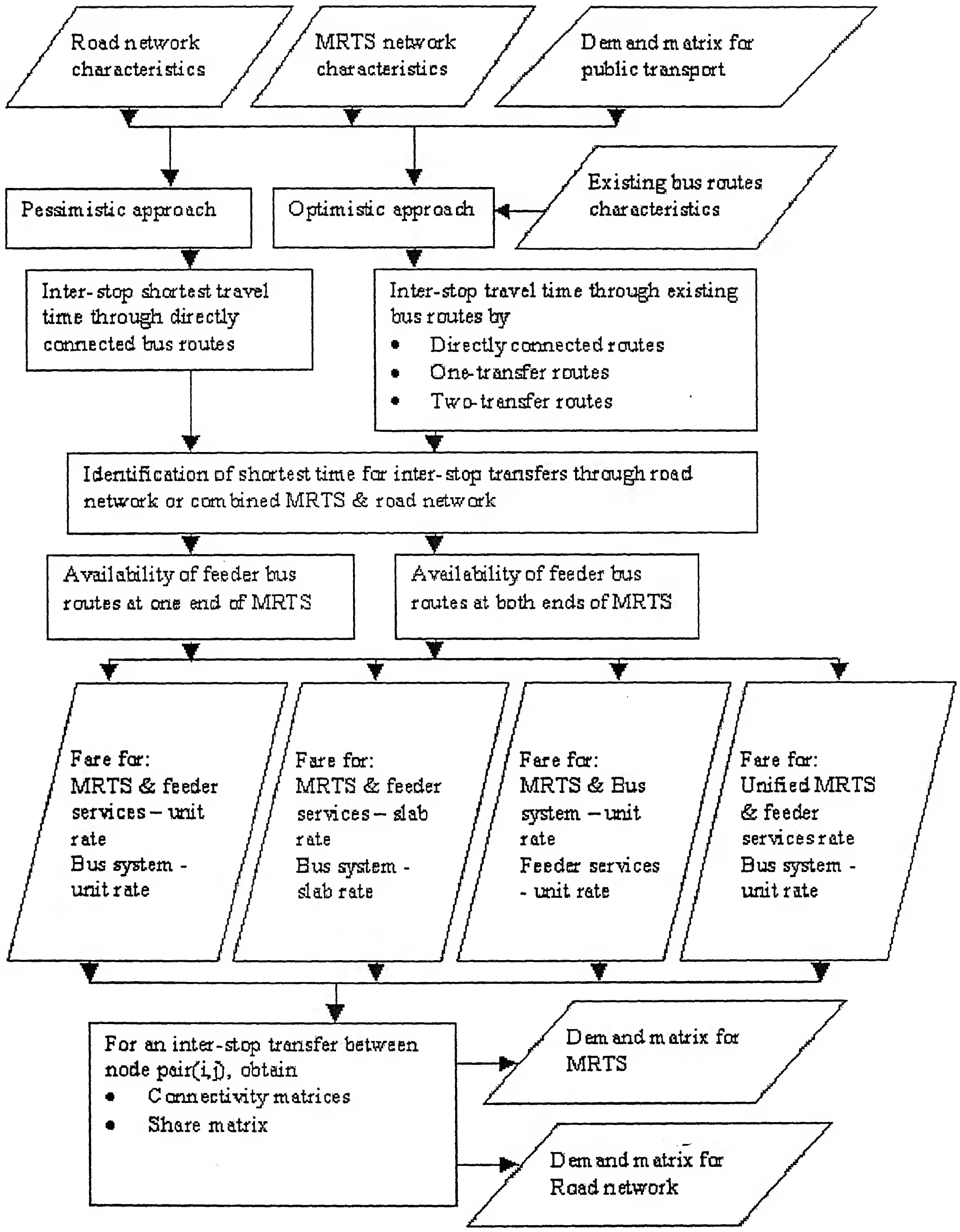


Figure 4.6: Model for Mode-Choice Analysis

(i) Maximum distance from the origin or destination to the MRTS station from where demand can be attracted and feeder routes are to be generated should be within a certain limit.

(ii) The distance traveled on MRTS corridor should be at-least some proportion of the total distance traveled between the origin and destination nodes.

(iii) The distance traveled on the MRTS corridor is greater than a certain minimum distance.

(iv) Availability of feeder routes on one end or both ends. A trip maker may walk to the MRTS station from the origin or from MRTS station to the destination, if the origin/destination nods are within about 500 meters from the MRTS station. For longer distances, the attraction to MRTS can only be through feeder services.

(v) Availability of limited existing bus routes or unlimited bus routes. All the O-D pairs of the network may or may not be touched by the existing bus routes. Unlimited bus routes will touch all the O-D pairs of the network. For certain O-D pairs the existing bus routes may also play the role of a feeder service.

Considering the inter-nodal transfers between existing bus transit system and MRTS/feeder bus service, the utility measures for each of the two modes is estimated; the parameters of travel time, travel cost and modal characteristics of the two modes are taken into consideration. The total travel time by the existing bus system and by the best possible path from the 25 different combinations of MRTS stations and O-D nodes as explained earlier is estimated. Accessibility of the inter-nodal transfers with respect to the MRTS is established and accessibility matrices are calculated. Considering the various constraints as cited above, two approaches named Optimistic approach and Pessimistic approaches have been specified for carrying out the mode-choice analysis in the model.

Optimistic approach deals with limited existing bus transit network that is already available whereas pessimistic approach deals with unlimited bus transit network that can be considered for calculations. Unlimited bus transit network may be defined as that in which all the bus stops in the network are connected to each other. Availability of feeder routes on one end of the MRTS or on both the sides of the MRTS has also been

considered. The model facilitates eight options for both the approaches based on the combinations of bus fare system, MRTS and feeder bus system, availability of feeder bus service either on one end of MRTS or on both ends. Table 4.1 presents the options available in the model for the analysis of mode choice.

Considering the above operational constraints, the mode choice analysis estimates the share of demand between the bus transit network and MRTS/feeder bus service for each O-D pair. For every nodal pair (i,j), the optimal route through MRTS is first determined by analyzing 25 alternative paths subject to various specified operational constraints. For the optimal path, the connected MRTS stations at both ends are identified in the [con_mrts (i,j)] and [sec_mrts(i,j)]. If inter-nodal transfer between 'i' and 'j' use MRTS system then [con_mrts (i,j)] depicts the connectivity between the node 'i' and MRTS station and [sec_mrts(i,j)] gives the connectivity between the second MRTS station and node 'j'.

Table 4.1: Options Available for Mode Choice Analysis

Option No.	Existing/unlimited bus System fare	MRTS & Feeder bus System		Availability of Feeder bus service
		MRTS fare	Feeder Bus fare	
1	Unit Rate	Unit Rate	Unit Rate	One end
2	Unit Rate	Unit Rate	Unit Rate	Both ends
3	Slab system	Slab system	Slab system	One end
4	Slab system	Slab system	Slab system	Both ends
5	Slab system	Inter MRTS-Station fare matrix	Slab system	One end
6	Slab system	Inter MRTS-Station fare matrix	Slab system	Both ends
7	Slab system	Unified MRTS & feeder bus fare (Inter-stop unified fare matrix)		One end
8	Slab system	Unified MRTS & feeder bus fare (Inter-stop unified fare matrix)		Both ends

The proportionate share of inter-nodal demand through MRTS is determined by the formulated Logit model and the matrix [share_mrts (i,j)] is generated. If there is a

feasible path through MRTS between 'i' and 'j', then share_mrts (i,j) lies between 0 to 1, otherwise share_mrts (i,j) = 0.

4.3.3 Estimation of Inter MRTS Station Demand

The estimated share of demand for the MRTS/feeder system for all node pairs can be used to determine the production and attraction of each MRTS station and also the inter-station demand. For each inter-nodal transfer the connectivity matrices [con_mrts (i,j)], [sec_mrts(i,j)] and proportionate demand share matrix for MRTS [share_mrts (i,j)] is obtained from mode choice analysis. If node 'i' is connected to the MRTS station through connectivity matrix [con_mrts (i,j)] and node 'j' is connected by connectivity matrix [sec_mrts(i,j)] to the other MRTS station , then the inter-nodal demand that use MRTS system are estimated as follows.

Inter_Nodal_MRTS (i,j) = Nodal_Demand (i,j) x share_mrts (i,j)

where Nodal_Demand (i,j) is the total inter-nodal public transport demand between node 'i' and 'j'

Inter_Nodal_MRTS (i,j) is that share of nodal demand (i,j) which is likely to move on the MRTS system.

[Share_mrts (i,j)] is the proportionate demand share matrix.

Using the Inter_nodal_mrts demand matrix, the demand at each MRTS station for feeder routes is estimated.

Let an Inter_nodal transfer as shown in Figure 4.7 between nodes 'i' and 'j' utilize the MRTS system between stations mt_1 and mt_2. This demand will be served as follows.

(a) From node 'i' to station mt_1 the movement could be by walk/feeder bus system.
(b) From station mt_1 to mt_2 the movement is by MRTS
(c) From station mt_2 to node 'j' the movement is by walk/feeder bus system.

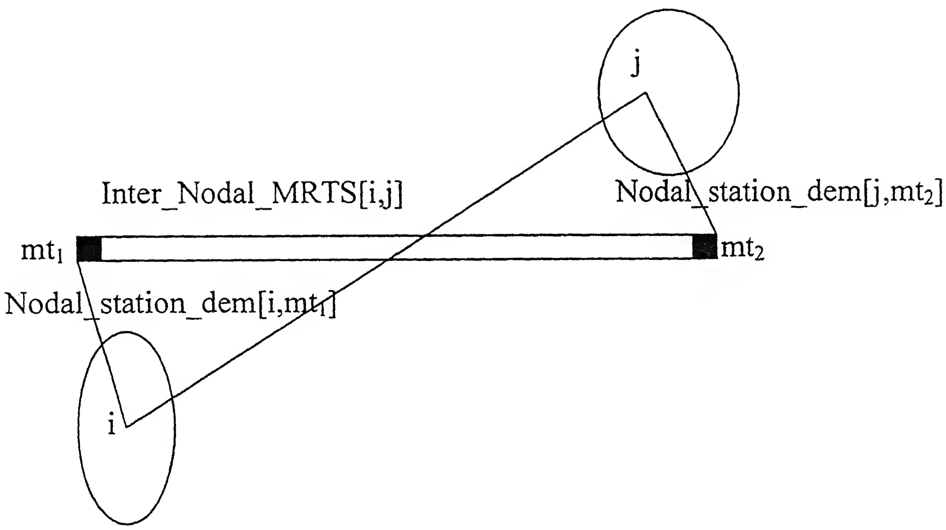


Figure 4.7: Inter-Nodal transfer

This inter nodal demand will pass through both the stations mt_1 and mt_2. The demand from a node 'i' or 'j' to an MRTS station are estimated as

$$Nodal\_station\_demand\ (i,mt_1) = Inter\_Nodal\_MRTS(i,j)$$

$$Nodal\_station\_demand\ (j,mt_2) = Inter\_Nodal\_MRTS(i,j)$$

The above demand for an MRTS station with reference to all the nodes in the influence area is generated.

4.3.4 Influence Area for MRTS stations

Each MRTS station has a certain geographical area from which trip makers will approach the MRTS station. This area, termed as the Influence Area of an MRTS station, depends upon the estimated travel demand from the stops to the MRTS station and the geographical layout of stops with respect to the MRTS station. This area needs to be demarcated for each MRTS station so as to facilitate the generation of feeder routes. The following models have been evolved to demarcate the influence area of each MRTS station in this work.

(i) Heuristic Model
(ii) Fuzzy Model
(iii) Neural Network Model.

Heuristic model for the demarcation of Influence areas is based on the micro-details of each inter-nodal transfer of demand through the MRTS system. Demarcating of influence areas by Fuzzy model involves the fuzzy-c-means clustering algorithm whereas the Neural Network model takes the help of self-organizing maps employing neighborhood criteria.

4.3.4.1 Heuristic Model

Demarcation of influence area of an MRTS station requires the scrutiny of each O-D pair for traveling through MRTS/feeder system and estimated demand. This has been effectively done subject to certain constraints described in the mode-choice analysis model. When some portion of public transport demand between a node pair ('i' and 'j') is estimated to move on MRTS system – between stations 'mt' and 'nt', then 'i' is said to be in influence area of nearest MRTS station 'mt' and similarly 'j' is said to be in influence area of MRTS station 'nt'. This analysis for all node pairs identifies the stops coming in the influence area of each MRTS stations. The total area encircling those stops will form the boundary of the influence area of a particular station. Figure 4.8 depicts the delineation of influence area by heuristic model. The demarcation of influence area also determines the total demand coming to the MRTS station from the nodes lying in the influence area and will be termed as the 'station load'. Depending upon the locations of O-D pair, a particular node may lie in the influence area of more than one MRTS station. This results in overlapping of Influence areas (Figure 4.9) of some MRTS stations. The model also facilitates the flexibility to the user to have different distance constraints for MRTS stations because the stations in CBD of the metropolitan area may have smaller influence areas whereas the stations away from the CBD area may have wider influence area.

4.3.4.2 Fuzzy Model

The fuzzy model for demarcation of influence area of MRTS stations makes use of the fuzzy-c-means clustering algorithm, which is explained in chapter-3. The influence area of a MRTS station may not have certain well-defined boundaries in the geometrical form.

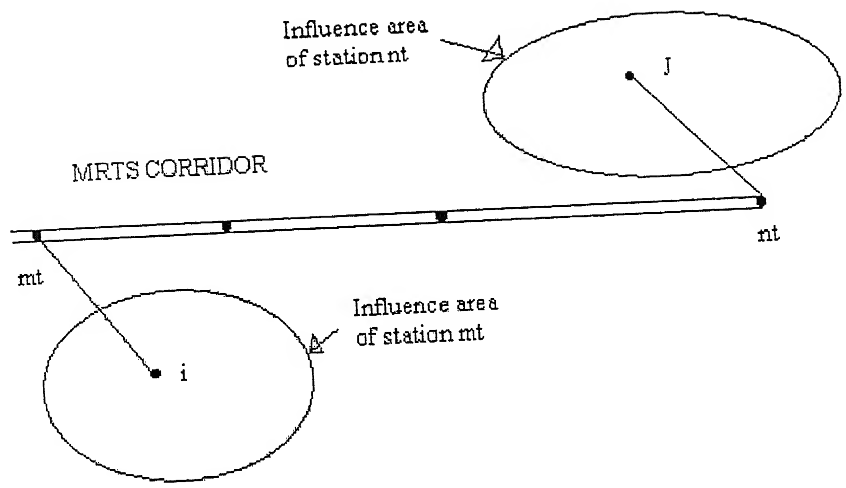


Figure 4.8: Influence Area of MRTS Station

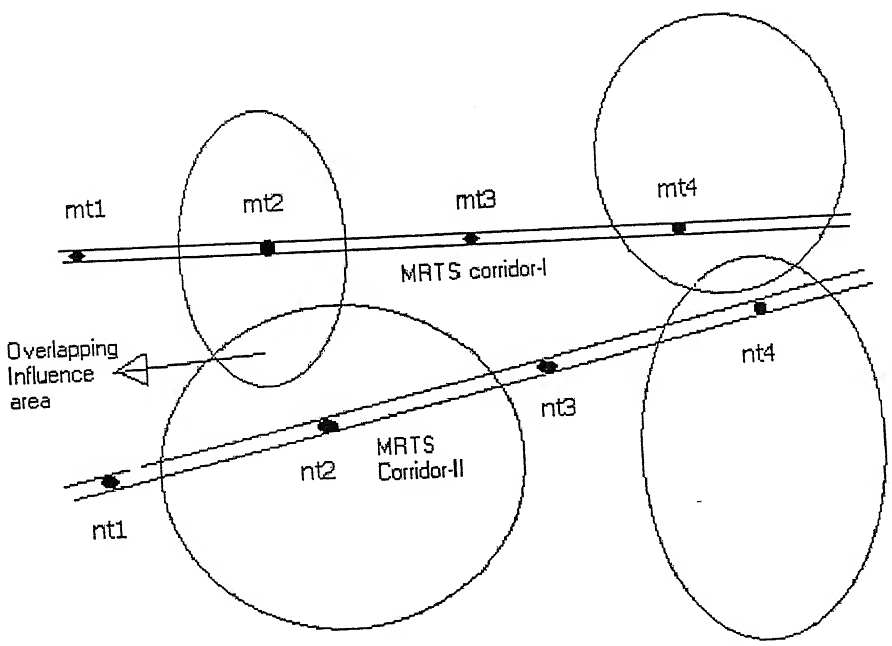


Figure 4.9: Overlapping Influence Area of MRTS Stations

In linguistic terms, it may be defined, that the passengers may come to the nearest MRTS stations from a certain geographical area with MRTS station as the focal point. But the term 'Nearest MRTS' in itself is fuzzy because the MRTS network is to be newly introduced. Since a trip maker may not be able to clearly identify the nearest stations for the origin - destination node pairs and there is ambiguity, vagueness and imprecision on the part of passenger willing to travel by a particular MRTS station, this motivated us to use fuzzy logic method to demarcate the influence area of MRTS stations.

Fuzzy-c-means clustering method, an iterative optimization method allows the degree of membership for different nodes in the study area for belonging to predefined number of clusters. This means the same node can occur in different clusters with different degrees of belongingness. The degree of belongingness or fuzziness is introduced with a weighing parameter in the optimization process. To start with a number of clusters 'C' is predefined for the set of 'N' nodes and the fuzziness parameter is assumed. The input parameters for grouping the 'N' number of nodes are coordinates of nodes, the shortest travel time from node to the MRTS station, and demand generated from the node for MRTS. The travel time and demand parameters may be combined together and represented as a ratio of (Shortest travel time from node to MRTS / Demand from node to MRTS). The partition matrix for clustering the nodes is initialized randomly. The cluster centers are calculated and the partition matrix is updated at each step. The matrix norm of two successive fuzzy partitions to a prescribed level of accuracy is compared, to determine whether the solution is good enough. As with many optimization techniques, though it may not be guaranteed to be global minimum, the best solution within a prescribed level of accuracy is obtained. The fuzzy partitions are de-fuzzified on the basis of Max-membership method and the largest element in each column of the partition matrix is assigned a membership of unity and all other elements in each column are assigned a membership value of zero. The predefined number of clusters is attached to the nearest MRTS stations through Euclidean distances. The attached clusters to the MRTS stations may be considered as the influence areas of the MRTS stations.

4.3.4.3 Neural Network Model

Self-organizing map is an unsupervised classification technique in Neural Networks, where no a-priori knowledge is assumed to be available regarding an input's membership in a particular class. A history of training is used to assist the network in defining classes and possible boundaries between them. In this mode of unsupervised learning, the network discovers for itself any possible existing patterns, regularities, separating properties, etc. and while discovering this, the network undergoes change of its parameters, which is called self-organization. The principal goal of the Self-organizing map (SOM) is to transform an incoming signal pattern of arbitrary dimensions into one or two-dimensional discrete map, and to perform this transformation adaptively in a topological ordered fashion. The algorithm responsible for the formation of the self-organizing map proceeds first by initializing the synaptic weights in the network. This can be done by assigning them small values picked from a random number generator, in so doing; no prior order is imposed on the feature map. Once the network has been properly initialized, three essential processes competition, cooperation and synaptic adaptation are involved in the formation of self-organizing map.

The weights of the neurons denote the centers of clusters in self-organizing map. The inputs to the model includes the number of nodes 'N' each represented as $X_k = \{x_{k1}, x_{k2}, x_{k3}\}$, where k= 1,2, ...,n are the number of centers that needs to be obtained. The three-dimensional input for each node represents the x-coordinate, y-coordinate and the ratio of (Minimum time to reach the MRTS station / estimated feeder demand). Random values for the initial weight vectors are chosen. A sample from the input space with a certain probability is drawn. The winning neuron is found out by using the minimum distance Euclidean distance criterion. The synaptic weight vectors of all the neurons are updated by a learning rate parameter. Gaussian neighborhood function centered around the winning neuron is varied dynamically during the updation process. The algorithm is continued, until no noticeable change in the feature map is observed. The number of nodes 'N' is grouped into a pre-defined number of clusters. These clusters are assigned to the nearest MRTS station with the simple Euclidean distance norm. The nodes in the

clusters assigned to a particular MRTS station will form the influence area for that MRTS station.

4.3.4.4 Comparison of the Heuristic Model with Fuzzy model/ Neural Network Model

(i) Heuristic model for the demarcation of influence area of MRTS stations deals the problem on a micro level, where each node pair is scrutinized and each node is assigned to a particular MRTS station. In case of Fuzzy and Neural network model, the predefined number of clusters is obtained from the given set of nodes and these clusters are then assigned to the particular MRTS station.

(ii) Nodes in the network can be assigned to more than one MRTS station based upon the location and demand, thereby overlapping the influence areas of different MRTS stations in the Heuristic model. Fuzzy and Neural Network models do not allow the same stop to be assigned to more than one MRTS station. However, the geographical areas enclosing these stops may overlap for different stations.

(iii) Based on the Mode Choice analysis and inter-stop transfer through MRTS for each OD pair, the influence area of each MRTS station obtained from Heuristic model contains the same stops. In case of Fuzzy and Neural network models, different stops can be assigned to a MRTS station based on the number of predefined number of clusters. If the number of predefined clusters is small, it may not be possible for some MRTS stations to have any influence area. As the number of clusters is increased, different MRTS stations may have different nodes in their demarcated influence areas. The output of these models thus depends on the number of predefined clusters.

(iv) Heuristic model has the facility of user interaction for demarcating the influence area of different MRTS stations based on their location. In the CBD area, small influence area can be demarcated for an MRTS station and wider influence area for MRTS stations away from the CBD. Influence area demarcated using Fuzzy and Neural Network models can be varied by

changing the number of predefined clusters irrespective of the location of MRTS station.

(v) Influence areas in case of Heuristic model can be worked out for one station at a time, whereas fuzzy and neural network models facilitate the demarcation of influence areas for all the MRTS stations in one shot after specifying the number of clusters.

4.3.5 Routing Model for Generation of Feeder Routes

Proper physical integration of MRTS and road networks necessitates the generation of feeder bus route paths within the influence areas of all MRTS stations. The feeder bus system has to serve all the nodes/stops in the influence area of an MRTS station. One end of a feeder route path is an MRTS station, while the other terminal is a bus stop within the influence area. When a feeder bus route starts from a terminal, it involves the boarding of passengers at all nodes of the path. All these passengers are to alight at the MRTS station. For the return trip, boarding is only at the MRTS station and alighting is at the nodes along the feeder path. For the nodes within a short distance, say half a kilometer from the MRTS station, feeder bus service is generally not availed and persons may walk to/ from the MRTS station.

In the proposed routing model, the generation of feeder routes is planned based on the considerations that route lengths are within specified limits, there is no excessive meandering from the shortest path, all nodes in the influence area of each MRTS station are served with minimum number of routes. Generation of routes is done sequentially. For each route, a set of feasible alternatives paths are generated and evaluated to select the optimal path based on the predefined criterion.

In the model, feeder routes are generated separately for each MRTS and the process is repeated to obtain the feeder bus routes for all stations of the MRTS network. The input parameters to generate feeder routes for an MRTS station are:

(i) Road network characteristics within the influence area of MRTS stations

(ii) List of nodes that can be considered as Terminals

(iii) Inter-nodal shortest distance and travel time matrices for the influence area

(iv) Generated travel demand matrix between nodes and MRTS

The strategy adopted to generate the paths of feeder routes for an MRTS station is shown in Figure 4.10. The steps involved in generating an optimal path of a feeder route for an MRTS station are:

(i) Identification of the Bus Terminal

(ii) Generation of alternative paths between Bus Terminal and MRTS station

(iii) Evaluation of alternative paths and selection of optimal path.

4.3.5.1 Identification of Bus Terminal (Step – I)

Generation of a feeder route in the influence area of an MRTS requires two terminating ends, one end of which is the MRTS station. The model for feeder routes generation starts with the identification of the second terminating end amongst the nodes, not served by already selected feeder routes, in the influence area of MRTS station. Firstly, the extreme farthest node in the influence area is picked up, because this node as terminal will provide accessibility to a large number of nodes in the influence area of MRTS station. The identification of bus terminal in the influence area of an MRTS station is also subjected to the following constraints.

(i) The node should be one of those nodes given as input, which can be made as bus terminal based on the necessary space available to accommodate the buses for parking etc.

(ii) The node should have sufficient generated demand to the MRTS station.

(iii) The distance from the node to MRTS station should be within the specified minimum and maximum limits of feeder route length. Because very short feeder routes may not be viable from operator point of view and longer feeder routes, involving lot of meandering, may not attract the commuters to the MRTS system.

(iv) The node cannot be made a terminal if an already generated feeder route for the MRTS station passes through the same node.

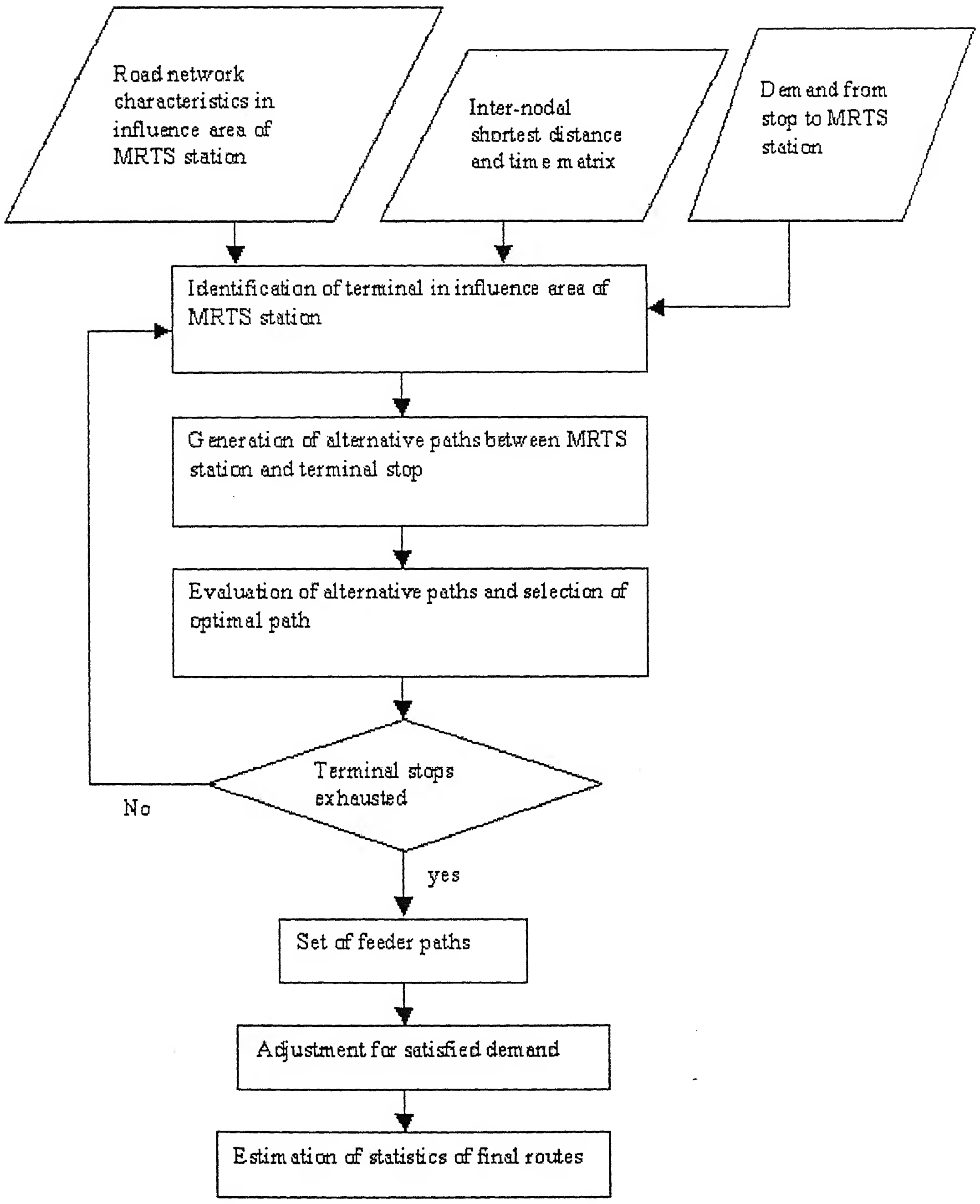


Figure 4.10: Routing Model for Generation of Feeder Routes for a MRTS Station

4.3.5.2 Generation of Alternative paths between MRTS station and Terminal (Step-II)

Alternative paths are generated between the MRTS station and the identified terminal. The first path generated is the shortest between the two terminals. The shortest path is deviated to a certain context by introducing a meandering factor, so that more nodes which are untouched and in close vicinity of the shortest path, can be accommodated in the alternative paths. Meandering away from the shortest path though permits more demand to be satisfied but too much excessive meandering increases travel time of commuters and also the cost of travel. Following constraints are therefore imposed for the generated alternative paths.

(i) Length of the alternative paths should not be more than a pre-specified value (shortest path distance x specified meandering factor).

(ii) There should not be any backtracking on the generated alternative paths.

4.3.5.3 Evaluation of Alternative paths and Selection of Optimal path (Step III)

The various alternative paths generated between the MRTS station and identified terminal are evaluated on the basis of 'Desire-passenger-km per km' criterion. The path, which has the maximum 'Desire-passenger-km per km' value, is selected as the optimal between the MRTS station and bus terminal. Passenger-km considers the actual distance traveled along the path of the route. Desire-passenger-km considered in this model is the product of nodal demand and the shortest distance from the node to MRTS station.

Figure 4.11 shows an alternative path with 'n' nodes and 'n-1' links. The following parameters are determined for each of the generated paths and 'Desire-passenger-km per km' is calculated.

(i) Passenger demand satisfied along the route

(ii) Demand satisfied per km

(iii) Desire passenger km per km

0 ——— 0 ——— 0 ——— 0 ——— 0 ——— 0

1   2   i   i+1   n

Figure 4.11: Alternative path of a Route

$$\text{Flow on link (i,i+1)} = \sum_{i=1}^{i}[Nodal\_demand(i)]$$

$$\text{Demand \_satisfied} = \sum_{i=1}^{n}[Nodal\_demand(i)]$$

$$\text{Demand satisfied per Km.} = \frac{Demand\_satisfied}{Route\ Length}$$

$$\text{Passenger\_km} = \sum_{i=1}^{n-1} flow\ on\ link(i,i+1) * length\ of\ link(i,i+1)$$

$$\text{Desire\_passenger\_km} = \sum_{i=1}^{n}[Nodal\_demand(i)] * \text{shortest distance (i,n)}$$

$$\text{Desire\_passenger\_km per km} = \frac{Desire\_passenger\_km}{Route Length}$$

The various criteria, which can also be used for selection of the optimal paths, can be Passenger_km, Average_link_density and Route Utilization Criterion. The criterion of Passenger_km involves the maximum passenger kilometer along the route, but if the demand satisfied along two different alternatives is same, then this criterion selects longer path giving setback to operator's objective. In average link density criteria, the alternative path, which maximizes the average link density, is chosen as the best. But in this criterion, every link is given equal weightage, whereas longer links should get higher weightage. Route Utilization Coefficient (RUC) criterion is another one, which can be used for the evaluation. Mathematically, it can defined as

$$\text{Route utilization coefficient (RUC)} = \frac{\sum_{i=1}^{n-1} flow\ on\ link(i,i+1) * length\ of\ link(i,i+1)}{Max.\ link\ flow * \sum_{i=1}^{n-1} length\ of\ link\ (i,i+1)}$$

But in the case of feeder routes, since the link flow goes on accumulating in the direction of MRTS station and reverse is the case in the opposite direction towards bus terminal, the criterion of RUC may not be representative of the best optimal path.

In the routing model, step-I to step-III generates an optimal path between MRTS station and an identified bus terminal. Another terminal is selected in the influence area of MRTS station subject to the constraints as specified in step I and the same procedure is repeated as stated in step-II and step-III. A set of alternative routes is generated and optimal route is obtained between the MRTS station and selected bus terminal. The process is repeated until all the terminals obtained by step-I are exhausted. In this way a set of optimal bus routes is achieved for the MRTS station. The process is repeated for all the MRTS stations and optimal feeder routes are generated for all the MRTS stations. There may be some nodes in the influence area of MRTS station, which remain untouched by any of the generated feeder routes. The demand of such nodes is transferred to the nearest feeder route within a certain distance constraint.

In the process of generation of feeder routes, a node, which has already been provided a feeder route, may also come on another feeder route. When there are more than one feeder routes passing through a node then each of the feeder routes will have some share of demand, which will in reality depends on the frequency of operation of routes. As the frequency of operation at this stage is still to be considered, the demand coming on to a route from a stop is shared equally among all the passing routes.

$$\text{Demand } (S_p) = \frac{\textit{Total demand from stop}(s)\textit{ to MRTS Station}}{\textit{Number of already selected feeder routes passing through stop}(s) + 1}$$

where, Demand(S_p) is the share of demand from stop , ‘s’ to the generated path ‘p’.

With the generation of optimal feeder routes, the connectivity of nodes for the MRTS station is also updated. The combined statistics of all the feeder routes are also obtained.

4.3.6 Scheduling Model for Generated Feeder Routes

Scheduling allocates the buses to the generated routes in accordance to the characteristics of the demand satisfied and the path of each route. A heuristic algorithm is developed for determination of the optimal allocation of buses on various generated feeder routes for all the stations of MRTS and is shown in Figure 4.12.

In a metropolitan city, the total hours of operation for public transportation system vary depending upon the demand and travel characteristics of the trip makers. The travel demand of the commuters also varies during the day:- being very high or low during certain periods. Two scheduling-periods, peak period and off-peak period, can be defined on the basis of variation of demand during different periods of the day. Since the peak hour requires more frequent service of buses due to higher load than the lean hours of the day, accordingly the operational period of public transportation is converted into equivalent peak hours by assigning weights to different hours of operation.

The number of bus trips to be operated on a feeder routes depends upon the passenger travel demand at stops along the generated paths, type of bus, scheduling period and desired level of service. A feeder path has one terminating end as the MRTS station and the other is the road terminal. As a feeder route moves from road terminal to MRTS station, the passenger flow on the links increases, as persons will be boarding at stops to reach MRTS station. Opposite will be the case, when movement is from MRTS station to road terminal. Link closest to the MRTS station will have the maximum passengers flow and one touching the road terminal will have the minimum flow.

Let a feeder bus route has n nodes along its path and the demand at a stop on the path is given by Nodal_Station_Demand (i,n), where 'i' is one of the nodes between node '1' and 'n-1' as shown in Figure 4.13 . This path has (n-1) links and the link flow on these links is estimated as passenger link flow (P_L_F). The number of trips on a route invariably depends on the maximum link flow. But there may be considerable variation of the passenger flows on the various links along the route. The design of services based on max flow would leave the bus underutilized on initial links and optimally utilized only

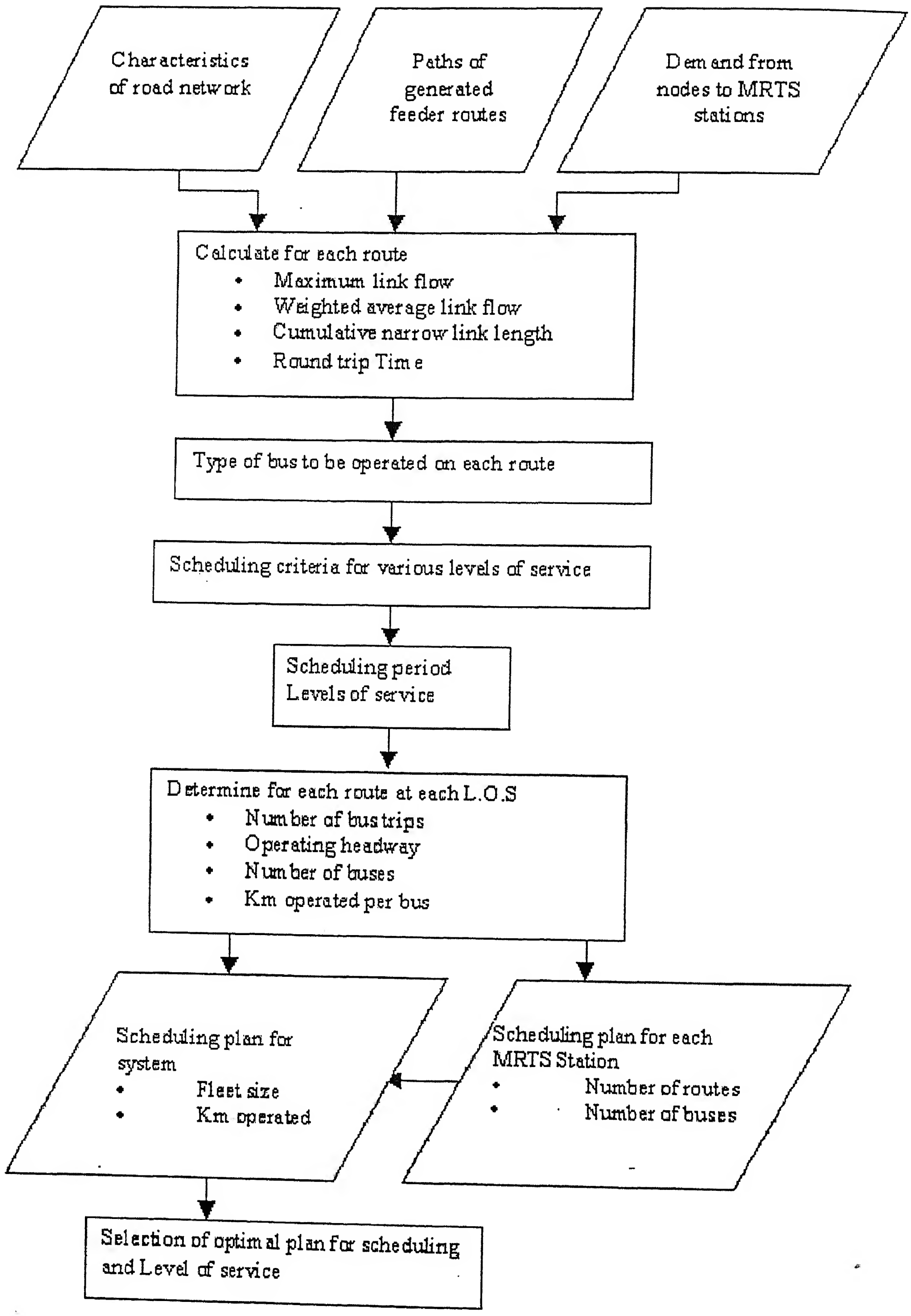


Figure 4.12: Scheduling Model for Feeder Bus Routes

for few last links. If the planning is done on the basis of minimum load then bus is over crowded on the last few links. To have a more realistic design, a parameter known as weighted average link flow is therefore, also introduced. The links are weighted as per their length and the weighted average link flow is determined.

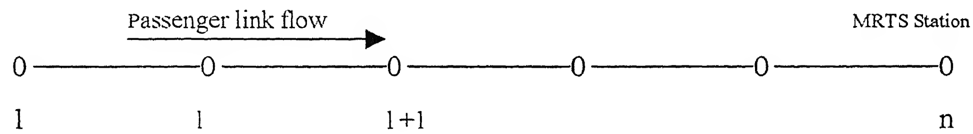


Figure 4.13: Feeder Route Path

$$Passenger\_Link\_Flow(l, l+1) = \sum_{i=1}^{l} Nodal\_Station\_Demand\,(\mathrm{i,n})$$

$$\mathrm{Maximum\_Link\_Flow} = \sum_{i=1}^{n} Nodal\_station\_demand(i, n)$$

or

$$\mathrm{Maximum\_Link\_Flow} = \mathrm{Passenger\_Link\_Flow(n\text{-}1,n)}$$

$$Weighted\_Average\_Link\_Flow = Passenger\_Link\_Flow(l, l+1)\frac{Link\ Length(l, l+1)}{\sum_{i=1}^{n-1} Link\ Length(l, l+1)}$$

All the generated feeder routes are to be operated at certain minimum frequency level or maximum policy headway. At the maximum policy headway, the minimum number of bus trips under peak conditions and the demand satisfied along the route is calculated.

$$\text{Minimum Number of bus trips} = \frac{Equivalent\ peak\ hours\ of\ operation}{Maximum\ policy\ headway}$$

Minimum Demand satisfied along the route

= Minimum Number of bus trips * Capacity of bus

4.3.6.1 Identification of Bus Type for Operation

Normally in a metropolitan city area, the standard bus with a capacity of 50 passengers is operated. For optimal operating conditions, this minimum demand along the feeder routes can be calculated. For those routes, where maximum link flow on the feeder route is less than the estimated minimum demand at maximum policy headway, the following two options are available.

(i) Increase the maximum policy headway. But this increase in maximum policy headway will further reduce the level of service and commuters may not be attracted to the feeder bus service.

(ii) Operate smaller size buses of lesser capacity. These smaller size buses termed as Mini buses of lesser capacity can be operated at the policy headway.

Further, some feeder routes may pass through certain links of the metropolitan area network, which may be narrow or congested especially in the congested CBD areas. These links may not be suitable for operation of standard buses. On these links, plying of mini buses is the only alternative available.

In the scheduling model, the type of bus to be operated on a route is selected first before estimating the number of trips. A Mini bus may be operated on a route subject to the following constraints on the route.

(i) The demand on the route is less than that required for a standard bus to be operated at maximum policy headway.

(ii) Total length of narrow/ congested road links along the feeder path is greater than one km.

(iii) The total length of narrow road links is more than 50 percent of the feeder route length.

4.3.6.2 Estimation of Bus Trips

Different levels of service are specified in the model for determining the trips of the two types of buses. Level of service can be defined in terms of

(i) Average bus load

(ii) Lower level of maximum bus load

(iii) Higher level of maximum bus load

The number of bus trips to be operated on a feeder route is dependent on the above-mentioned parameters. Bus trips 'Est_T1' are estimated by dividing the weighted average link flow by the average load for each type of bus. Bus trips 'Est_T2' and 'Est_T3' are also estimated by dividing the maximum link flow by the lower and higher levels of maximum bus load for each type of bus respectively. These estimated bus trips are compared among themselves and the bus trips to be operated on a feeder route is calculated.

$$\text{Estimated Trips 'Est\_T1'} = \frac{Weighted\_average\_link\_flow}{Average\ bus\ load}$$

$$\text{Estimated Trips 'Est\_T2'} = \frac{Maximum\_link\_flow}{Lower\ level\ of\ \max imum\ bus\ load}$$

$$\text{Estimated Trips 'Est\_T3'} = \frac{Maximum\_link\_flow}{Higher\ level\ of\ \max imum\ bus\ load}$$

The number of bus trips is to be selected out of Est_T1, Est_T2 and Est_T3 so that all constraints of the level of service are satisfied.

If Est_T1 $\geq$ Est_T2 then Bus_trips = Est_T1,

If Est_T1 $<$ Est_T2 and Est_T1 $\geq$ Est_T3 then Bus_trips = Est_T1

If Est_T1 $<$ Est_T2 and Est_T1 $\leq$ Est_T3 then Bus_trips = Est_T3

4.3.6.3 Estimation of Round Trip Time

The round trip time for a route includes running time in each direction, total halt time at the stops, and the lay over time at the MRTS Station and Road Terminal. The running time is estimated considering the Vehicle operating speeds in the area of operation. Halt time depends on the number of passengers boarding/alighting at the stops and the number of stops along the route. An average halt time of 20 seconds is adopted in this model with regard to all the stops whose boarding/alighting is to take place. For any nodes within half a km of MRTS Station, the passengers are not expected to use feeder bus system and these nodes are excluded from estimation of demand and halt time. A layover time is

provided on the MRTS stations and at the route terminals. The total round trip time for a bus (Round_Trip_Time) is estimated as:

Round_Trip_Time = 2 * (Running time + Halt time + Layover time)

4.3.6.4 Estimation of the Operational Parameters

Knowing the period of scheduling and the bus trips desired to be operated during that period, the required headway is

$$Headway = \frac{Period\_Time}{Bus\_trips}$$

The actual operation of the buses may desire a certain minimum and maximum value for the headways. The headway for the feeder routes should not be less than the headway of operation for the MRTS system. Further if the headway is too large then it does not provide the desired service for which the system is being planned. Knowing the desired headway and the constraints of minimum and maximum values, the actual headway at which the service may be operated is determined.

Headway operated = Max [Minimum policy headway, headway] or
Min [headway, Maximum policy headway]

Knowing the actual headway for operation, the number of vehicle trips in each direction for the scheduling period is estimated as

$$Trips\_operated = \frac{Scheduling\ \ Period}{Headway\ \ operated}$$

The number of buses required for the desired scheme of operation on a feeder route is estimated as

$$No\_of\_buses = \frac{Round\_Trip\_Time}{Headway\ \ operated}$$

The number of parking lots at the MRTS station for the route under consideration can be calculated as

$$\text{No of parking lots} = \frac{Layover\_time\_in\_\min utes}{Headway\_in\_\min utes} + 1$$

Passengers Served by the Route - The total passengers processed per day by the feeder routes equals the maximum passenger link flow. The passengers served for any period of operation are determined considering the period of operation and the demand factor for that period. Total waiting time for all the passengers served by the route is also estimated.

Total Km. operated by the route and for each bus on the route is estimated as

Total_km_operated = 2 x Route length x Trips_operated

Km_Operated per Bus - This defines the utilization of the buses along the route

$$Km\_operated\,per\,Bus = \frac{Kms\ operated}{No\_of\_Buses}$$

4.3.7 Restructuring of the Existing Bus Routes

The commissioning of a new transit mode like MRTS changes the mode choice pattern of the city. Accordingly, the existing bus route network should undergo changes to cater to new travel pattern. MRTS would provide service on trunk routes with high passenger demand and buses would act as feeders to MRTS. Routes running parallel to MRTS corridors would become redundant and some existing bus routes may overlap with the newly generated feeder routes. Therefore it is necessary that such existing routes be identified and restructured so as to ensure optimum utilization of the transit modes. The following strategy is formulated for restructuring of existing bus routes.

- Establishing a band along MRTS corridors to check for overlapping routes
- Identifying overlapping bus routes
- Fixing paths of restructured routes
- Estimation of demand transferred from bus routes to MRTS

4.3.7.1 Establishing a Band along MRTS Station to Check for Overlapping Routes

A bus route may be considered to overlap with MRTS if it travels close to the corridor over a certain minimum length. Closeness to the MRTS could be with respect to a certain lateral spacing. In the model, a band parallel to MRTS corridor with a lateral spacing of some specified value on each side may be taken up for study.

4.3.7.2 Identifying Overlapping Bus Routes

A bus route may be considered to overlap if it passes through the established band for a specified length. Let a route r with bus terminals st_1 and st_2 enter the band at an intermediate stop I, leaves the Band at stop J and goes to st_2. Let the nearby MRTS stations for stops I and J are mt_1 and mt_2 respectively. Bus route is overlapping over the distance between the MRTS stations mt_1 and mt_2. The overlapping length is the inter MRTS distance between stations mt_1 and mt_2.

For the bus route to be considered for restructuring, the overlapping distance is to be

- Greater than a certain minimum specified length
- More than a specific percent of total bus route length.

4.3.7.3 Fixing Paths of Restructured Routes

Based on the above considerations, if a route r turns out to be an overlapping one, then restructuring of the route is done. For restructuring of the route, the first step is to fix the path of route to be restructured. The route starts from terminal st_1 and reaches up to MRTS station mt_1 as shown in Figure 4.14. If there is a major stop s_1 close to mt_1, the route could be extended and terminated at mt_1 subject to that the length of the new route is within operational limits. The path of this route will now be (st_1,...., I, ...,.mt_1,...,.s_1)
In the similar fashion, starting from the other end of route st_2 and going up to MRTS station mt_2, if there is a major stop s_2 close to mt_2, the route could be extended and terminated at s_2 subject to the maximum new route length. The path of this route will be (st_2,...., J, ...,.mt_2,...,.s_2). The restructured route curtailed at nearest bus terminal to MRTS station also becomes a feeder route and its demand gets transferred to MRTS.

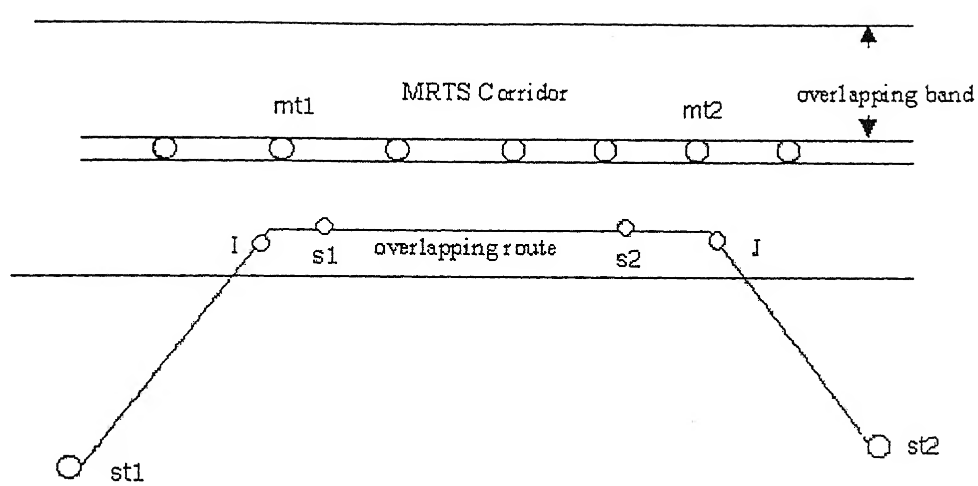


Figure 4.14: Restructuring of Existing Bus Routes

4.3.7.4 Estimation of Demand Transferred from Bus Route to MRTS

A stop (K1) between I and J along the existing route with a spacing of at least 3 km from I is identified. The demand originating between terminal st_1 to stop I and terminating between stop k_1 to terminal st_2 will be transferred to MRTS. This demand will move on to MRTS between mt_1 and mt_2 stations. Identical analysis is done for the opposite direction with demand originating between (st_2 and J) and terminating between (k_2 and st_1).

Demand matrices for the MRTS are adjusted. This exercise is repeated for all the existing routes, which are overlapping with MRTS corridor. Prioritization of routes for implementation could be based on statistics of the generated routes.

4.3.7.5 Modification of Input data

Generation of optimal feeder routes for all MRTS stations, their scanning and scheduling gives a fairly good amount of idea for the existing bus routes, which are to be restructured due to the introduction of a new transit mode namely MRTS to the already existing public transportation system. Due to the restructuring of existing bus routes, the

input data related to existing bus routes is to be modified and utilized for further analysis of feeder routing and scheduling models.

4.3.7.6 User Interaction for Modification of Feeder Routes

The routing model as discussed earlier is applied for the revised data. The program system has the facility to make adjustments in the paths of the generated feeder routes necessitated due to certain operational constraints. Each generated feeder route is tested for any modification through graphic display of the paths and its statistics. The set of finally selected modified paths of all the feeder routes are scanned to obtain the various statistics of interest. These routes are then finally considered for preparing the scheduling plan of Feeder system at different levels of service.

4.3.8 Integration of Feeder Bus Transit System with GIS

The models developed for feeder bus transit system involve both spatial and non-spatial database. The Decision Support System tries to integrate the database with geographical information system. The spatial database of feeder bus transit system for a metropolitan area relates to:

- Mapping of road network and MRTS network.
- Location details of bus stops and MRTS stations.
- Location details of influence area of MRTS stations.
- Paths of existing bus routes
- Paths of feeder routes
- Paths of overlapping routes and restructured routes.

The non–spatial database of interest to integrate the feeder bus transit system with GIS consists of

- Passenger trip production and trip attraction at a bus-stop
- Link-lengths of road network and MRTS network
- Speed on road links and MRTS links
- Details of existing bus-routes
- Details of Feeder routes
- Details of overlapping and restructured routes

4.3.8.1 GIS Interface and Query Facilities

The GIS interface will combine the maps and results together and help to extract any relevant information on route network links, bus stops, MRTS stations, influence area of MRTS stations, passenger travel demand and fleet characteristics.

The Decision Support System uses ARCVIEW 3.1 (GIS tool) package from Environment System Research Institute (ESRI), USA. This software is primarily designed to allow the user to view and query spatial data. Arc view has its own macro language; AVENUE, the ability to interact with SQL database servers, and the ability to use platform specific links with the software. The input database is converted into shape files by AVENUE script and the output is viewed in the arc view platform. This interface can perform *what-if and where-if kind* of analysis. The programming is done through scripting in AVENUE (Arc view) and Visual Basic.

Arc View organizes data in such a way that it can be envisioned as digital layers or coverages of information. MRTS stations, bus stops, intersection points and other locational points can been depicted in the first layer. Road network and MRTS network may be drawn as the second layer. The existing bus routes and the newly generated feeder routes obtained through the optimization model may be shown in the various digital layers. The Influence areas of various MRTS stations and the overlapping corridors can also be drawn in other layers.

The queries, which a user can perform on GIS platform, can be related to Bus stop, MRTS station, road and MRTS network, Existing bus routes, characteristics of Feeder routes, overlapping routes with the MRTS corridor and characteristics of restructured route. Briefly, these queries can be explained below.

Queries for Bus stop characteristics

To start with, the first digital layer of map depicts the presence of the Bus stops. A user can get the information for trip production, attraction and presence of nearest MRTS station from a queried bus stop. Existing bus routes or generated feeder routes by the

feeder bus route model, which are passing through a Bus Stop, can also be queried along with operational details.

Queries for MRTS Station characteristics

An MRTS station can be queried for the influence area, in which the feeder routes for the MRTS station are generated. The station load from the influence area of MRTS station can be searched and the number of feeder routes passing through the MRTS stations can be filtered out. These feeder routes are provided with all the operational details, which can be immediately known to the user with the clicking of mouse. Total number of buses plying during the peak period and mid-day period on the feeder routes passing through MRTS station can be searched. A commuter can easily walk for half a kilometer to reach to bus stop from an MRTS station. Therefore, any bus route within half a kilometer along with the operational details from the MRTS station can be queried. Total number of parking lots for buses at MRTS station can also be searched.

Queries of Road and MRTS Network characteristics

A metropolitan city after the implementation of MRTS normally possesses a very large network of roads and MRTS corridors. Queries can be done on the length and speed on the road and MRTS links. Information regarding the status of road links in the form of one–way or two-way can be obtained.

Queries of Existing Bus routes characteristics

Existing bus routes can be searched for the bus stops en-route, originating and destination stops. The length of the existing bus route along with the operational details like running time, waiting time and journey time on the route can be queried.

Queries for Feeder Bus routes characteristics

Feeder bus routes can be filtered for the bus stops en-route, originating and destination stops. The length of the feeder bus route along with the operational details like running time, waiting time and journey time on the route can be queried.

The GIS interface and query facilities developed in the Decision support system will enable the user to understand the working of the model system and also help to make better decisions.

4.4 PROGRAM SYSTEM

The developed methodology for planning of feeder bus routes for MRTS system can be adopted for a large network of a metropolitan city. The methodology includes a number of heuristic and optimization models to estimate the travel demand on MRTS stations, delineation of Influence area for MRTS stations, routing and scheduling of feeder routes of all MRTS stations. All these models are interlinked and the integration of these models is adopted by development of a program system for decision-making. The decision support system includes a number of different modules and their interconnections are shown in the flow chart of Figure 4.15. A brief description of the modules is presented below.

- INPUT

This module is meant for keeping all the input files that are required for the execution of the model.

- FIRST

This module prepares for model execution and arranges the data given in input files in sequential form.

- NETWORK

Under this module, the existing road and the proposed MRTS network is prepared. The Cartesian X and Y coordinates of the nodes in the network are required for the network display on the screen. This module facilitates displaying the network in parts and zooming around a node or MRTS station. Existing bus routes can be visually displayed one by one in this module.

- SH_DIST

This module generates the shortest inter bus stop distance matrix by available bus routes and shortest inter bus stop distance matrix by road. Shortest inter stop-MRTS station distance matrix for all bus stops and MRTS stations is also generated.

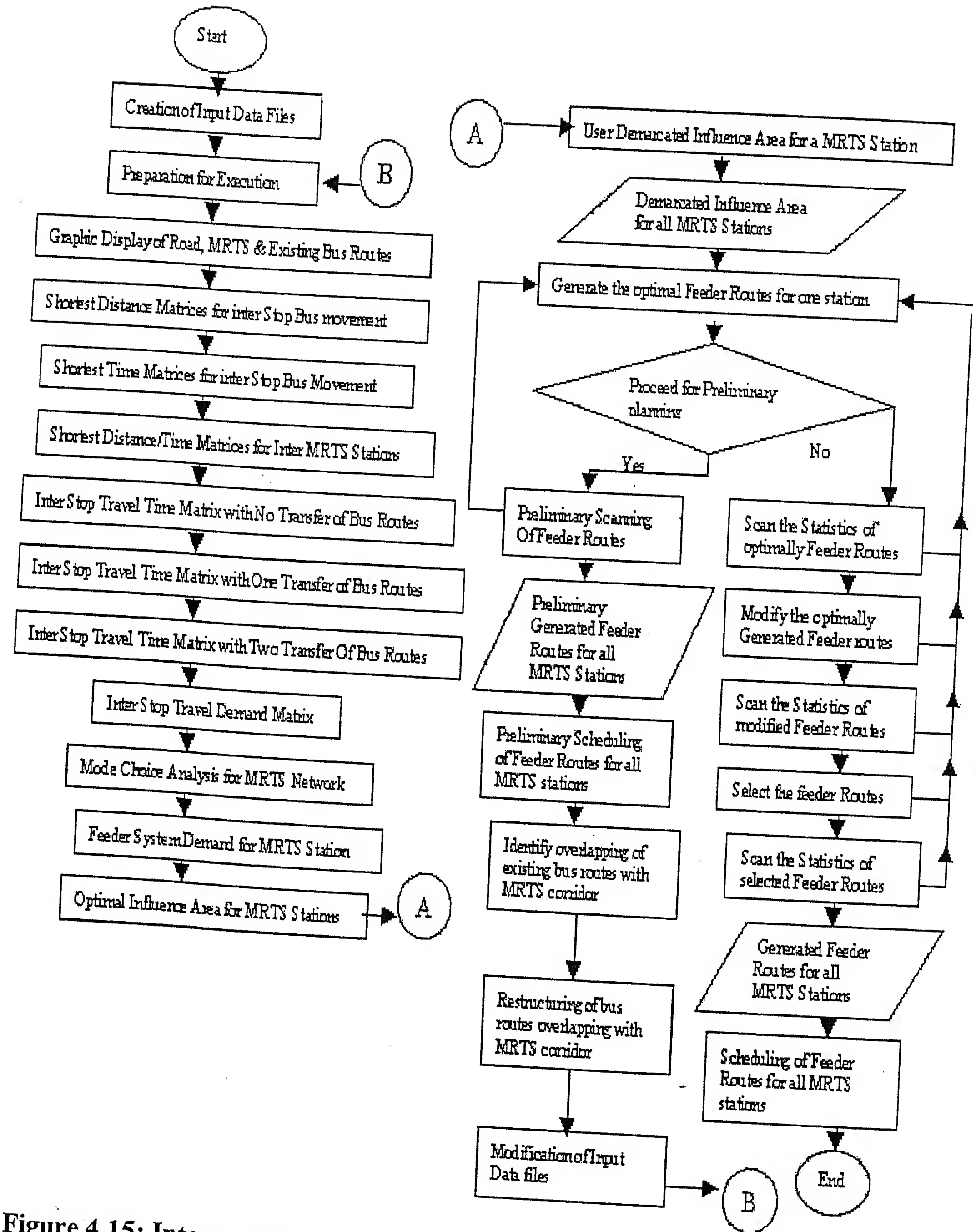


Figure 4.15: Interconnection of different Modules for Decision Support System

- SH_TIME

This module generates the shortest inter bus stop time matrix by available bus routes speeds and shortest inter bus stop time matrix by road. The existing route paths, the bus stops in the network and the speeds forms the major input in the module.

- MRT_DIS

This module computes the shortest distance and time matrix among MRTS stations.

- TRANSF_0

This module with the help of existing bus routes calculates the inter-stop accessibility matrix with zero transfers.

- TRANSF_1

This module with the help of existing bus routes calculates the inter-stop accessibility matrix with one transfer.

- TRANSF_2

This module with the help of existing bus routes calculates the inter-stop accessibility matrix with two transfers.

- BUS_TIME

The output of the three modules Transf_0,Transf_1 and Transf_2 are combined to give one inter stop accessibility matrix with zero, one and two transfers with respect to existing bus routes.

- Demand

The zonal OD matrix is converted into bus stop wise OD matrix, if bus stop OD matrix is not available. The traffic generating potential of each bus stop falling in the zone and zonal OD matrix is the major input for this module.

- MOD_CHOC

This module runs the mode choice model. It considers the parameters of travel time, travel cost, transfer penalty, waiting time and then assigns the proportion of demand on to MRTS and bus system.

- F_DEMAND

Based on the proportion of demand assigned to MRTS under the previous module, this module calculates the total expected feeder demand.

- OPT_INF

This module generates the optimum influence areas for all MRTS stations.

- INFLUENC

This module depicts on the map, the influence area of a MRTS station as generated above. The bus stops that fall in the optimal influence area are highlighted.

- GENERATE

This module generates the paths of feeder routes for all the MRTS stations.

- SCAN_OPT

The routes generated in the module 'GENERATE' are preliminary scanned in this module and various statistics such as route length, demand satisfied, pass-km/km etc. are calculated for each generated route.

- SCH_OPT

This module prepares the preliminary scheduling plan for peak and off-peak periods for different levels of service. Apart from assigning buses on the routes, the statistics related to route performance such as frequency of the route, trips/day, km/bus/day etc. are calculated in this module.

- OVERLAP

This module identifies those routes that are overlapping with the proposed MRTS alignment or the existing bus routes.

- RESTRUCURE

The overlapping routes identified in the module overlap are restructured in this module.

- SCAN

The input data files are modified after the restructuring of overlapping routes. The feeder routes are again generated in the module 'GENERATE' and are scanned in this module. The various statistics of the route like route length, demand satisfied, pass-km/km are calculated.

- MODIFY

The routes generated in the module 'SCAN' can be modified in this module. The modification can be in terms of curtailment, extension or diversion of the generated feeder route.

- SCAN_MODIFY

The modified routes in the module 'MODIFY' are scanned to calculate the statistics of all the routes including modified routes, as the modification can affect the statistics of the other routes.

- SELECT

In this module, the user is given an option to select the routes based on the statistics of the routes generated in module 'SCAN' and the modified routes generated in module 'SCAN_MODIFY'. The routes selected here serve as the final set of generated routes for any particular station.

- SCAN_SELECT

This module scans the final set of generated routes and calculates the statistics for this set of routes.

- SCHEDULE

This module prepares the final scheduling plan for peak and off-peak periods for different levels of service.

- OUTPUT

In this module, all the important relevant output results from different modules are stored. These results are further used in integrating the output of heuristic models with the ARCVIEW platform.

- GIS_INP

This module generates the necessary database to be presented through maps by ARCVIEW interface.

- GIS_OUT

In this module, all output files in the form of database from module 'GIS_INP' are stored for further analysis by ARCVIEW programming language AVENUE.

4.4 SUMMARY

In this chapter, a 'Decision Support System' of feeder bus routes for 'Mass Rapid Transit System' of a metropolitan city is developed. This interactive Decision Support System has a series of Heuristic optimization models. The mode choice model to estimate the travel demand matrix for MRTS and existing bus network is discussed. Routing model to

generate the feeder bus routes within the influence area of each MRTS station is developed. A heuristic model to prepare the scheduling plan for feeder bus routes, with different types of vehicles, to meet the expected feeder trip demand at various levels of service is presented. Model for restructuring of existing bus routes, which are operating within the influence area of MRTS stations is discussed. Finally, the integration of feeder bus transit system with GIS environment is presented. The chapter concludes with the presentation of interconnection of different modules developed for the Decision Support System.

CHAPTER - 5

CHOICE OF STUDY AREA

5.1 INTRODUCTION

The rapid urbanization compounded by population explosion has changed the urban transportation scenario to a great extent in different countries. Massive growth in population coupled with stepping up of commercial, economic and administrative activities and also the expansion of geographical area of cities leads to conversion of walk trips into vehicular trips and the travel mode changes from cycles, two wheelers and IPT modes to a bigger unit like a bus. With further increase in city size and traffic volume, the need arises for a high capacity mode like an intra-urban rail service. For small cities with a population of one million or so the planning of bus transit system with destination-oriented approach caters to generated trips reasonably well. But for a metropolitan city, it leads to a bus transit system with lengthy criss-cross routes, which is difficult to operate. For metropolitan cities, where rail based public transport system exists, lack of coordination between bus transit network and railway system leads to a considerable increase in intermediate and private transport. The limited space on roads and heavy growth of traffic results in traffic congestion, reduced travel speed and poor level of service. The efficiency of trains and public buses can be enhanced by co-ordinating the two systems. Operational integration of railway system and bus transit system through feeder routes can take care of entire journey of commuters.

A design methodology based on Hub and Spokes approach is evolved in Chapter 3 for design of bus transit network for large cities. This methodology involves a series of optimisation models. For metropolitan cities, where rail based public transport system is existing or in the process of execution, a decision support system for routing, scheduling

of feeder bus routes for MRTS and to restructure the existing bus routes is developed in Chapter 4. To apply the models developed in the previous chapters, it is proposed to take New Delhi, as the study area.

5.2 NEW DELHI, THE STUDY AREA

5.2.1 General

Delhi became the seat of Government of India in 1911 when the then Imperial Government shifted its capital from Calcutta to Delhi. Construction work of New Delhi started in 1912 under the supervision of renowned city planners and architects, Sir Edwin Lutyens and Sir Herbert Baker and the seat of the Government was shifted to this place in 1931. The city has continued to grow since then at a fast pace. New Delhi, the capital of the largest democracy is the focus of the socio – economic and political activities of India. The genesis of Delhi's growth lies in the increasing urbanization, which continues to offer the increasing employment opportunities and thus in turn the pace of migration.

The national capital territory of Delhi covers an area of 1483 sq. km. and is a Union Territory with all powers of State Government. The population of Delhi has increased manifold during the last fifty years. Table 5.1 presents the growth of population in Delhi since 1951 along with proportion of urban population to total population. The population of Delhi was 1.74 million in 1951, which has increased to 13.2 million in the year 2001. It is observed that the population has been growing at the rate of approximately 4 percent per annum since 1961. The city has been showing the trend of increasing urbanization and 90 percent of total population is urban.

Table 5.1: Population Growth in Delhi

Year	Population (Million)	Urban Population Percent	Annual Growth Rate (percent)
1951	1.74	82	6.63
1961	2.66	89	4.31
1971	4.07	90	4.34
1981	6.22	93	4.34
1991	9.42	90	4.2
2001	13.2	90	4.06

Source: Census of India, 2001

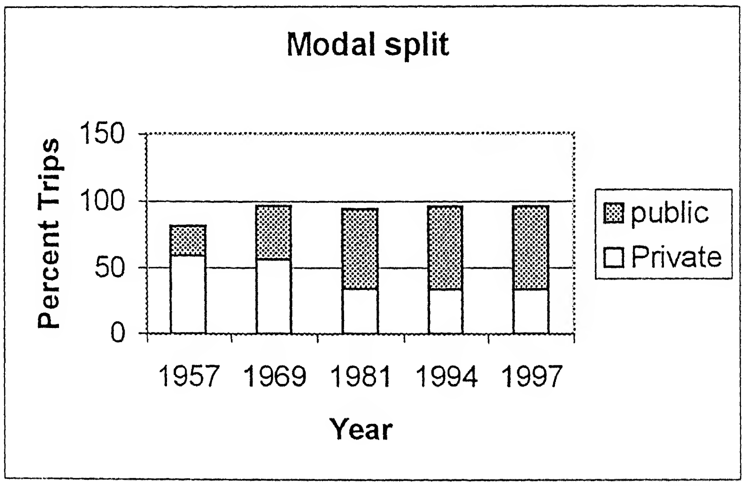
5.2.2 Traffic Characteristics

The traffic on roads of Delhi is a heterogeneous mix of cycles, scooters, buses, cars and rickshaws jostling with each other. This has resulted in a chaotic situation. The registered number of vehicles in the city of Delhi has been increasing over the years. In fact, the total number of vehicles in Delhi is more than the total number of vehicles in the other three metropolitan cities of Mumbai, Calcutta and Chennai put together. The number of vehicles in Delhi was about 2.8 million in 1997. The number of two-wheelers among the total vehicles has been increasing sharply over the years. The number of two-wheelers is about two third of total vehicles. The result is extreme congestion on the roads of Delhi, slow speeds of vehicles, increase in road accidents and fuel wastage. The number of accidents has been increasing at an alarming rate with over 9000 accidents recorded in 1997. Motorized vehicles alone contributes about two thirds of the atmospheric pollution in the city.

5.2.3 Public Transportation System

The public transport system of Delhi is primarily road based with the share of rail based public transport being negligible. No other city in India witnesses such massive passenger trips performed by road based public transport system as in Delhi. Intermediate public transport in the form of minibuses and eight-seat autos are the alternative support to the bus system. The bus system in Delhi is a mix of public and private buses. The public buses are operated by Delhi Transport Corporation (DTC), whereas private buses are operated by mostly individual agencies both on Stage and Contract Carriage (Chartered buses) permits. In 1997, about 7.0 million passengers, including passengers using more than one bus per trip, is being carried by stage carriage buses while 0.7 million passengers are being carried by contract carriage buses, operating as charted buses. The regular Stage Carriage bus system comprised of 4000 private buses under State Transport Authority (STA) and 3870 DTC buses including 1200 private buses under administrative control of DTC. About 5000 Chartered buses provided point-to-point service during peak hours supplementing these regular bus services.

Figure 5.1 shows the modal split of passenger trips in Delhi. It is observed that the share of public transport system has been showing an increasing trend over last four decades. The share has increased from 22.4 percent in 1957 to 62 percent in 1997, a very significant increase indeed and indicates the importance of bus transit system in Delhi.



Source: Bus Route Rationalization Study for Delhi, RITES 1997.

Figure 5.1: Modal Split of Passenger Trips in Delhi

5.2.4 Existing Route Network Of Delhi

The city of Delhi having Ring and Radial Road network has expanded in all directions. With the growth of the city over the years, a number of activity centers have developed and spread all over the city. This development has affected the travel pattern of the city. Till early seventies, the bus route network of the city suffered from poorly designed route network that had grown haphazardly over the years. In 1974, DTC introduced the concept of direction oriented route network replacing the destination oriented route network of the old system. The distinctive features of these services were good frequency, straight routes and a number of efficient change options at the central node. The direction oriented route network of DTC introduced in 1974 got disturbed in the process of providing links to upcoming areas with major activity centers resulting in large number of lengthy zigzag routes and gross under utilization of available resources.

In 1992, the privatization of bus service was adopted in large scale, under which Red Line Scheme was launched for giving 3000 permits to private bus operators. The routes designed for the operators were changed on ad hoc basis to meet the demands of the bus operators and this again impaired the route network resulting in destination oriented lengthy, zigzag routes. STA has about 3500 and DTC has 811 planned routes. Out of these STA is operating 1052 and DTC is operating 334 routes. Each route has on an average 15-20 en-route bus stops.

5.3 HISTORY OF PLANNING MASS RAPID TRANSIT SYSTEM

The city of Delhi with a population of about 13.2 million should have had an MRTS network of at-least 100 KM by this time, if the standards adopted by the western countries are taken into consideration. But in actuality, it is still at the take-off stage. Delhi has all the ideal dress-up for an excellent MRT System to be brought in. It has wide roads covering 23 percent of the city area, where road possession for construction is not difficult. Delhi also has an unassailable railway network comprising two rings and six spurs within the urban area. Unfortunately, these rail assets are not presently fully utilized, as its share of commuter traffic is only two percent. The history of planning a Metro rail project for Delhi dates back to nineteen seventies. Some earlier studies have been conducted through various organizations for planning of Delhi MRTS. The major recommendations of these studies of are given in Table 5.2.

5.4 MASS RAPID TRANSIT SYSTEM NETWORK

To rectify the overall situation and to improve the public transportation system in Delhi, the Government of National Capital Territory of Delhi, in equal partnership have set up a company named Delhi Metro Rail Corporation Ltd. under the Companies Act, 1956 to construct 33 Km of Metro Rail tracks in Delhi by 2005 in first phase as given in Table 5.3.

The commissioning of MRTS corridors is expected to start from December 2002 and all the sections in first phase are likely to be operational by the year 2005. The implementation program for the first phase is given in Table 5.4.

Table 5.2: Major Recommendations of Earlier Studies of Delhi MRTS

Year of study	Name of study and Agency	Major Recommendations
1969-70	Comprehensive traffic and transportation studies of Greater Delhi (CRRI, New Delhi)	Developed mathematical models to project travel demand and recommended mass rapid transit system for Delhi with total underground length of 51.30 Km
1973	Concept plan of Town and country planning office	Suggested underground length of 58 Km of MRTS and 195 km of surface corridors
1974	Metropolitan transport team study, Ministry of urban development	Planned a well knit mass rapid transit system comprised of 36 Km of underground corridors aligned two axes North-South and East-West corridors and 96 km of surface rail corridors.
1975	Study by metropolitan transport project (Railways) Ministry of Railways	Concept plan envisaged a network of 58 km underground and 195 km of surface corridors.
1984	Perspective development plan 2001 (Delhi development Authority)	Recommended for a multi modal transport system comprising of 200 km of light rail system, 10 km of Tramway, an extension to surface rail system and feeder services
1986	Urban Arts commission	Recommended for the development of existing Ring Railway with three radial underground MRT corridors of 20 Km.
1986	MRTS for Delhi- Report of study group, Ministry of railways	Alignment for East-West corridors connecting Vivek Vihar and Vikaspuri for 36 km only was suggested
1987	MRTS for Delhi- Report of Task force of Ministry of Urban development	Adoption of M-Bahn magnetic levitation system on a trial basis.
1992	Integrated Multi modal rapid transport system of Delhi. (RITES, New Delhi)	Recommended three-component system comprising of rail corridors, metro corridors and dedicated bus way totaling to 184.5 km
1995	Integrated mass rapid transport system for Delhi. Modified phase- I (RITES, New Delhi)	Recommended MRTS network of 52 km with underground metro corridor of 11 km and surface / elevated rail corridor of 41 km.

Source: www.delhimetrorail.com

Table 5.3: Revised Phase-1 of Delhi MRTS

S. No.	Section	Length	No. of Stations
East – West Corridor			
i.	SHAHDARA-ISBT-TRINAGAR	9.83	10
ii.	TRINAGAR- BARWALA	12.24	11
Total		*22.07*	*21*
North– South Corridor			
iii.	VISHVA VIDYALAYA-ISBT	4.5	4
iv.	ISBT- CENTRAL SECRETARIAT	6.5	6
Total		*11*	*10*

Table 5.4: Phasing Schedule for Implementation of MRTS

Year	Month	Section
2002	December	SHAHDRA-TIS HAZARI
2003	June	TIS HAZARI – TRI NAGAR
2003	December	TRI NAGAR – BARWALA
2004	June	VISHWA VIDYALAYA – ISBT
2005	March	ISBT – C. SECRETARIAT

5.5 FIELD SURVEYS FOR DATA ACQUISITION

The bus transit network of Delhi over the times has deteriorated to a great extent and suffers from numerous operational problems. Some of these problems can be enumerated as:

(i) Lengthy, Zig-zag and overlapping destination oriented routes

(ii) Mal distribution of buses along different routes.

(iii) Quite a few newly developed residential/commercial centers are not adequately catered to.

(iv) Long journey hours, including long waiting time at bus stops.

(v) Low frequency of buses on many routes

(vi) Ad hoc changes in route network as well as frequency of operation.

These chronic problems forced the Delhi administration to think about the restructuring of existing bus routes. Delhi mass rapid transit system (MRTS) is also in planning and execution stage. Some preliminary work in these areas was done at IIT Kanpur in association with RITES (Source: Route Rationalization and Time Table Formulation Study for Bus System of Delhi, March 1998 & Planning of Feeder Public Transport System for Phase-I of Delhi MRTS, August 2001, RITES). RITES conducted the different surveys in the recent past and the data collected is made available for this work.

Field surveys of the road characteristics were conducted by RITES to obtain the relevant data for building of the combined MRTS/ Road network, which can be utilized for planning MRTS, feeder bus services and bus transit services. Surveys were done in the following three steps to prepare the required inventory information.

Step 1: Preparation of the transit network for the study area

This survey was conducted to identify the nodes with medium to heavy generation of public transport demand and select the road links connecting these nodes.

Step II: Identification of road links for plying of bus services

All the links of the network obtained in step-I were evaluated and those feasible for plying of buses were identified for further investigations. This field survey was done by moving over all the links and recording the following data:

- Link length
- Number of lanes in each direction of travel
- Bus stop location on the link
- Curb parking, if any, and its location on the link
- Roadside encroachments to cause obstructions and their locations
- Nature of land use development along the link
- Sight distance limitations, if any, and their locations
- Traffic control measures along the link
- Level of traffic control (Light, medium, heavy and very heavy)

- General nature of traffic composition with reference to predominance of passenger and goods vehicles and share of slow moving vehicles
- Operating flow condition i.e. free flow, stable flow, unstable flow, congested flow etc.
- Suitability for movement of standard / mini buses

The analysis of the data recorded in the above survey helped to decide the suitability of each link for inclusion in the final network.

Step III: Recording of traffic flow characteristics for the network obtained in step II

Traffic characteristics on all the links identified in step-II were studied by moving car method. Data was recorded with the aim to analyze for following traffic flow characteristics:

- Traffic flow and composition during the peak period
- Link travel time and average operating speed
- Amount of delays on major intersections and total intersection delays
- Level of service on the road like free flow, stable flow, unstable flow, congested flow etc.

5.6 PREPARATION OF NETWORK FOR STUDY AREA

Data obtained in the various steps of the field surveys provide a complete inventory of road and traffic characteristics of the network for the study area. Based on the survey data various nodes and links of the transit network are identified. The identified nodes are coded in a systematic pattern, and links are described through the nodes at the two ends. In all 1542 nodes on the road and MRTS network are selected with 7269 links passing through them. This network is of very large magnitude as shown in Figure 5.2.

The combination of the identified nodes and links fully describe the various characteristics of the network. The network is completely digitized for all nodes and links. A node is identified by its code, X and Y coordinated of its location. A link is identified by the codes of two nodes at its ends and the distance between them. For proper representation of the network some dummy nodes are also introduced. This

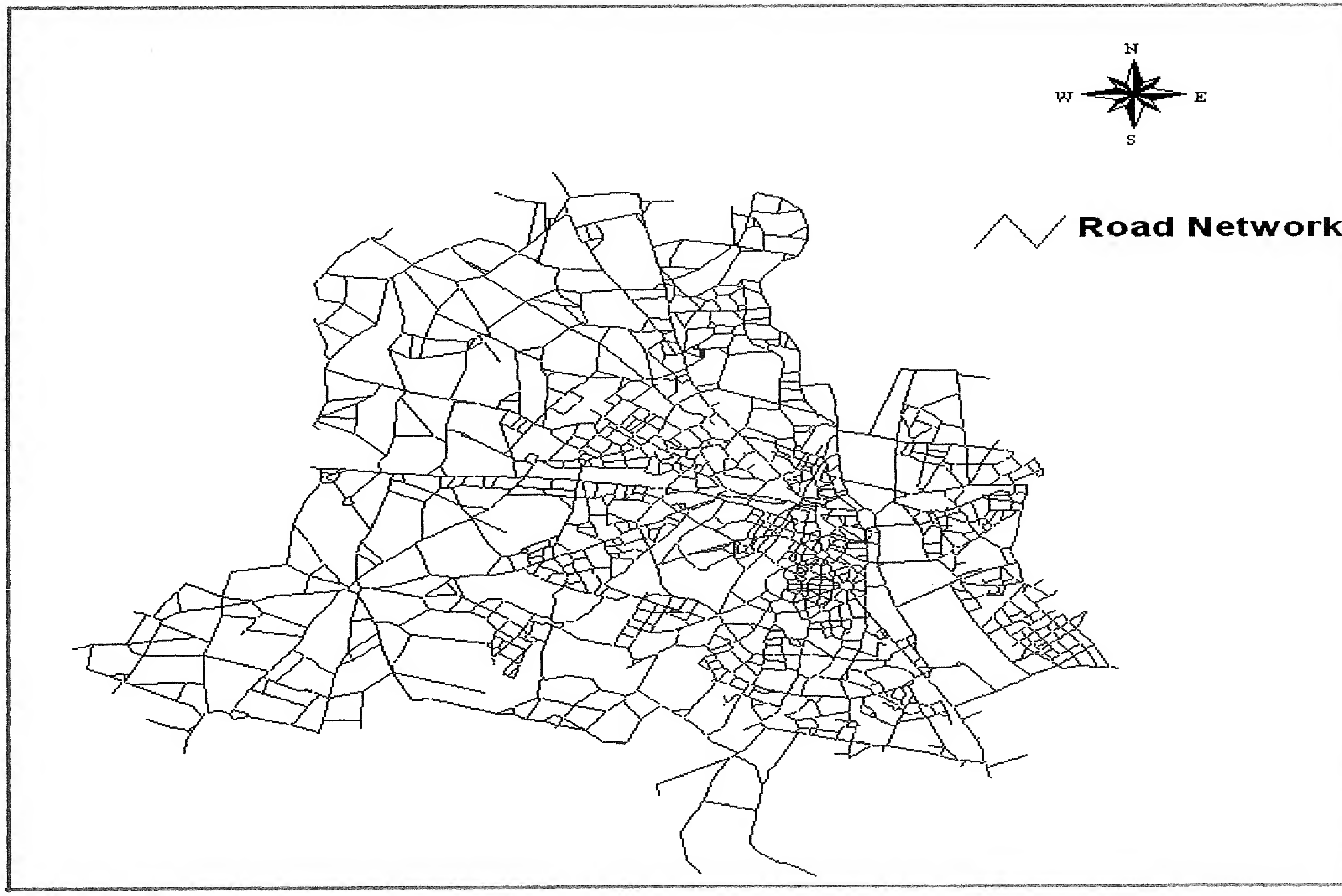


Figure 5.2: Existing Road Network of Delhi

digitization of the network is useful for plotting the complete representation of the network.

The speeds on each road link of the network are determined. The bus journey speeds, excluding the halts, vary considerably over the network depending on the location, cross sectional details of the link and traffic flowing on it. These speeds are found to vary between 15 to 30 Kmph.

5.7 SUMMARY

In this chapter, general and traffic characteristics of the study area chosen is discussed. The public transportation system and existing route network of Delhi is discussed. The history of planning mass rapid transit system through various agencies over the years is presented. In the last, various field surveys conducted by RITES to prepare the transit network and its related features are discussed.

CHAPTER – 6

PLANNING FOR BUS TRANSIT NETWORK OF DELHI

6.1 INTRODUCTION

The bus routes evolved over the years in most of the cities in developing countries rely on 'Destination-oriented' approach. To satisfy the trips produced due to haphazard development of cities, the destination-oriented approach results in a bus transit network too complex to be handled easily. Bunching on certain sections of the network due to overlapping of routes is a common feature. High concentration of buses on certain sections and scanty on others causes irregular distribution of headways along the route. As the size increases, the complexity of the network increases exponentially. For large networks, devising operational plan on such a complex transit network is really a tedious job.

In order to alleviate the problems encountered by operators and trips makers on destination-oriented routes, Hub and Spokes approach, which is easy to understand and better for operational plan of large network, is devised. Hub and spokes approach makes use of direction-oriented approach and is heavily dependent on the location of hubs that are widely spread out in the city area. Trip makers desirous of traveling from origin to destination in the city area can make use of inter-hub routes for longer distances, which are faster, having high frequency and easy to understand. Smaller distances within the influence area of hub can be managed with the secondary routes.

The methodology devised for hub and spokes approach is implemented on a large network of New Delhi and consists of the following components.

(i) Selection of optimal Hubs and delineation of Influence area for each Hub.

(ii) Estimation of Inter-hub and Intra-hub demand.

(iii) Generation of the path of Inter-Hub routes.

(iv) Generation of the path of Secondary routes.

(v) Determination of service frequencies for Inter-hub routes.

(vi) Determination of service frequencies for secondary routes.

6.2 SELECTION OF OPTIMAL NUMBER OF HUBS

Optimal location of hubs is the backbone of the hub and spokes transit network system. These hubs should be widely spread out in the whole city area so as to properly serve all parts of the city, produce high demand and have sufficient influence area. These hubs should be separated from each other by sufficient distance so that high frequency faster inter-hub routes, which are viable from operator as well as trip maker point of view, can be operated. Selection of optimal hubs is attempted with the objective to minimize the total passenger travel time in the bus transit system. The objective function, as illustrated in study methodology, involves a number of terms, which are estimated for the network. The estimation of waiting time requires the operational plan of the bus transit system. But at beginning of the design process the waiting time calculations are done on the basis of policy headways.

As the network for Delhi is very large, heuristic models are therefore involved in the design process and the location of optimal hubs is generated by the following three-step procedure.

(i) Partitioning of stops in clusters

(ii) Location of hub within a cluster and its influence area.

(iii) Selection of optimal hubs

6.2.1 Partitioning of Stops in Clusters (Step-I)

The city of New Delhi, represented by 1542 stops of the bus transit network, is to be partitioned into a number of clusters. Two design methods have been proposed in the study methodology to partition these stops in a predefined number of clusters. The first method relates to Fuzzy-c-means (FCM) clustering in 'Fuzzy Logic' and the second belongs to Self-organizing maps (SOM) in 'Neural Networks'.

Fuzzy-c-means clustering method uses a fuzziness parameter m, which is taken as 1.5. The partition matrix is initialized for all the 1542 stops, each stop represented by Cartesian coordinate and the demand. The FCM algorithm operates up to a prescribed level of accuracy, which is assumed as 0.001 to determine whether the solution obtained is good enough. The stops are grouped in a defined number of clusters.

Self-organizing map in neural networks partitions the 1542 stops on the basis of neighborhood criteria. The initial neighborhood parameter $\sigma_0 = 0.1$ is adopted in the work for self-organizing map whereas the final neighborhood parameter adopted is $\sigma_f = 7.0$. The learning rate parameters of $\eta_0 = 0.8$ and $\eta_f = 0.01$ has been taken up as the initial and final values for the algorithm. The initial weights of the neurons denoting the cluster centers are randomly generated. The input parameters for each stop are the Cartesian coordinates and demand. A sample from the input space with a certain probability is drawn and the winning neuron is found out. The synaptic weight vectors are updated by a learning rate parameter 'η'. During the updating process, the Gaussian neighborhood function centered around the winning neuron is varied dynamically. The algorithm is continued until no noticeable change in the feature map is observed. All the 1542 stops are grouped into a defined number of clusters. To identify the optimum number of clusters, experiments are made for different groups varying from 25 to 60. For each group, clusters are identified by both the methods of Fuzzy-c-means and Self-organizing map.

6.2.2 Location of hub within a cluster/Influence area (Step-II)

The clusters obtained through the FCM and SOM method represent specified geographical areas in the city. These geographical areas are to be represented through hubs from each cluster. The objective is to locate the hub in a cluster so as to minimize the 'Total passenger-Km' from all the stops to the hub in the cluster. Since the network of Delhi is very large, an algorithmic approach as discussed in the study methodology, is applied for the location of hubs within the selected clusters. For each cluster, five bus stops of highest demand are considered as probable terminal stops or hubs. Choosing one bus stop among these five bus stops, 'Total Passenger-km' is calculated for all the stops in a cluster. The probable terminal stop having minimum 'Total Passenger-km' is selected as a hub for the cluster. All the stops in the cluster are bounded in a geographical area, which is defined as the influence area of the selected hub. The same procedure is to be applied for all the clusters and hubs are obtained for the entire network.

Table 6.1 presents the hubs obtained through Self-organizing map for different set of clusters varying from 25 to 60. The influence area of a cluster is a geographical shape enclosing the stops lying in a cluster. As the number of clusters increases, the influence area will be relatively smaller area. Table 6.2 gives the distance of the farthest stop in the cluster from the hub. These results are given for each of the hub in a set of clusters varying from 25 to 60 using Self-organizing map. It is observed that in case of 25 clusters the maximum distance of the farthest stop from the hub is 18.1 Km, whereas the minimum distance of farthest stop is 5.6 Km. For the case of 60 clusters, the corresponding values are 16.8 Km and 2.5 Km. The mean value of the distance for the farthest stops from the hub varies 9.4 Km for 25 clusters to 6.0 Km for 60 clusters. Table 6.3 gives the comparison of mean distance of farthest stops from hub as obtained from both self-organizing map and fuzzy-c-means clustering methods and is shown in Figure 6.1. This comparison is made for different set of clusters. It is observed that as the number of clusters is increasing, the mean distance of farthest stops from hub goes on decreasing for both the methods. Further the mean distances by both the methods are relatively closer indicating the potential of both the methods to form similar type of clusters.

Table 6.1: Hubs obtained through Self Organizing Map

Number of Clusters	Number of Hubs	Code of Hubs
25	25	1181 1469 1482 1477 96 1268 1508 1491 1398 1425 1495 1388 1500 315 279 1377 1443 852 667 1484 793 752 1510 544 460
30	30	1181 1268 1035 997 715 1469 1359 1388 1456 1442 1155 1491 667 1431 1524 1429 1477 1453 1533 1441 1482 1449 1499 1398 1501 96 333 61 1484 1365
35	35	1181 1509 1482 1368 96 1142 1385 1470 1371 26 1285 1460 1354 1408 3 983 1388 1382 728 61 887 1495 1412 667 1405 1463 1357 698 1392 1363 1016 752 1524 544 460
40	40	1363 460 559 627 793 450 1437 1412 752 1515 1382 667 1533 1357 1002 1452 185 1438 1374 1463 1484 1475 1499 898 1251 273 1 1493 1446 1271 96 1354 1508 1272 1212 1482 192 208 1469 1181
45	45	1212 986 1377 793 627 1181 1268 1456 752 1510 1469 1446 1495 698 544 1144 1124 1388 1430 1410 120 25 444 1404 667 192 376 1107 1398 517 1482 54 319 852 1501 96 1368 185 1460 460 26 273 1350 230 1363
50	50	1181 1469 192 374 1482 1212 1285 1470 1520 96 1142 1508 32 6 333 983 1107 1460 61 292 1025 724 1371 1506 1484 898 1438 1383 1398 1363 1443 1412 667 1413 1471 841 953 1077 451 460 887 752 1533 544 545 1016 793 1504 559 627
55	55	96 1482 192 1469 1181 148 82 1470 1149 1197 107 1449 32 1481 1230 1425 1371 1492 1359 1223 279 1356 315 1287 1251 1460 1405 1382 290 984 1438 185 1494 919 1465 1066 1390 667 1443 841 450 1437 1533 887 1463 1363 559 698 1433 1377 460 627 863 793 1008
60	60	1006 793 627 1510 1471 1363 1377 1512 863 543 523 460 967 1515 953 667 517 1413 1495 1357 1533 1494 1066 1366 844 1388 919 1398 185 724 986 1446 322 1383 1483 234 1268 1408 1460 58 1350 292 1223 1508 1107 1475 6 107 1236 1134 1470 1354 275 97 1181 1469 120 192 1482 91

Table 6.2: Variation of Distance of Farthest Stops in different Clusters (Self-organizing Map method)

	Distance of farthest bus-stop from the hub in a cluster							
Number of Clusters	25	30	35	40	45	50	55	60
Hub Serial no.								
1	17861	5820	11340	7216	4148	5144	4372	5144
2	7629	10400	9373	17092	9373	5042	7478	3146
3	5605	13323	4479	5211	7326	3766	7587	8834
4	9817	4799	9810	9554	11591	16604	7239	16627
5	6328	11698	5236	9806	7868	8714	10820	9897
6	6664	11481	7354	12655	4789	6451	4356	6416
7	7898	4891	5890	3011	7393	13323	9765	4368
8	7696	9662	4743	5001	6132	8012	5257	6601
9	5968	17380	4331	6177	9210	3998	4603	5487
10	17380	18802	10861	6579	4422	5236	4087	10225
11	18090	8885	5689	3935	11980	4102	3484	6811
12	11795	9464	7483	5554	5695	3871	4681	5331
13	7933	5910	15652	7696	5001	4898	5150	3596
14	5788	6560	10363	5515	3335	6579	6579	4045
15	8821	10709	14003	9164	6328	2477	5023	5519
16	4846	5367	19700	8454	4705	5407	3859	3089
17	10676	5902	4717	7265	3935	5655	7696	6579
18	9568	6835	5021	25041	4577	7696	3542	5023
19	18538	9887	8474	10312	7898	6450	4340	2824
20	11358	5309	9542	7144	7696	7671	4887	7696
21	5823	9640	4012	8204	3720	4151	3412	8903
22	9443	9262	5074	6250	7305	4758	5604	5126
23	5063	7155	9073	8474	3439	7483	12907	4355
24	10523	14578	7933	5446	9785	15652	3904	3678
25	12722	11358	6063	5212	7024	5980	7638	4373
26		6166	5174	3007	8454	4212	8454	7959
27		5023	6469	3599	8283	5232	6697	11688
28		6995	8185	5435	16345	9063	6894	4873
29		7797	4865	7714	4941	8454	8793	4884
30		5571	8829	4632	8474	8283	19434	7182
31			9741	9675	5443	19700	5427	8454
32			14587	8271	11795	8474	8099	6894
33			5499	5520	7468	2509	3813	9989
34			12664	10286	2788	4908	8474	16850
35			7797	7192	5940	2577	4873	2975
36				6912	3160	3079	7021	5525
37				4614	4582	4778	3198	3283
38				10523	8493	3272	2544	8474

39				5053	9640	2916	5174	2482
40				4002	3340	3481	8264	6213
41					8271	10676	5421	3968
42					9556	6781	5265	5083
43					4825	4708	5154	3403
44					5072	10286	2468	3042
45					6150	5313	5796	5551
46						4563	3143	5619
47						3856	8222	3750
48						6367	5635	6033
49						3671	8271	7055
50						3729	7660	5579
51							8045	5442
52							10286	9178
53							4222	4062
54							2695	2536
55							4666	3011
56								10523
57								4715
58								4191
59								3826
60								3773
Mean	9379.15	8887.63	8286.45	7560.07	6837.66	6400.16	6225.05	6029.3

Table 6.3: Comparison of Mean Distance of Farthest Stops from Hub for different Clusters

Number of clusters	Mean distance of farthest stop from hub (in Km)	
	Self-organizing map	Fuzzy-c-means
25	9.4	10.2
30	8.9	9.3
35	8.3	8.1
40	7.6	7.7
45	6.8	6.9
50	6.4	6.5
55	6.2	6.3
60	6.0	6.3

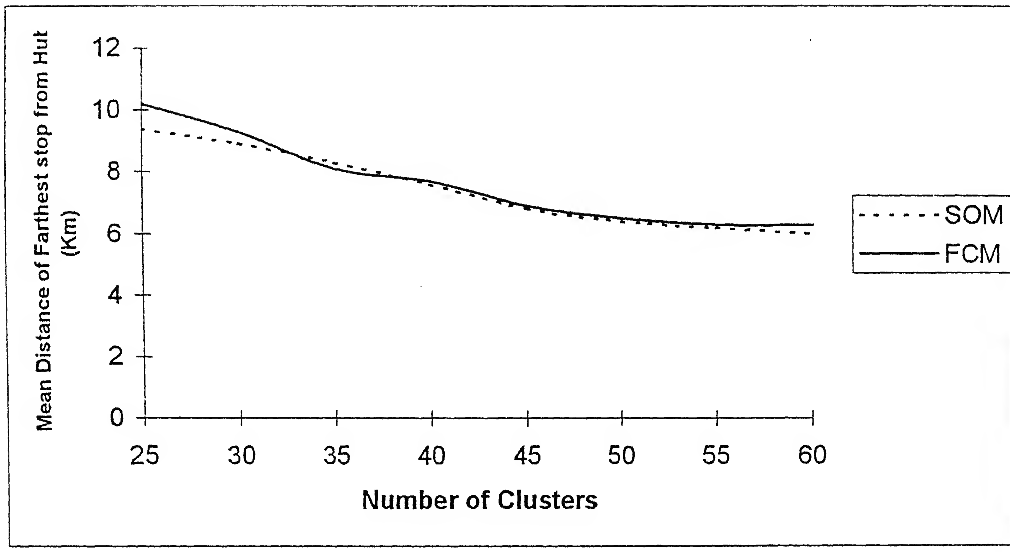


Figure 6.1: Comparison of Mean Distance of Farthest Stops from Hub for different Clusters

6.2.3 Selection of Optimum hubs (Step-III)

In the first two steps, the transit network of Delhi has been partitioned in a number of predefined clusters (25-60); hubs are selected, and influence area has been delineated for each of these clusters. This step aims to select the optimal number of Hubs, which can then be used for generation of bus routes based on hub and spoke system. Optimum number of clusters is based on minimizing the total passenger travel time of the entire network.

The originating stop and the destination stop for any traveler may lie within the influence area of same cluster or in different clusters of the transit network. When both origin and destination stops lie within the influence area of same cluster, then there is no need of any transfer through the hubs. But if the origin and destination stops lie in influence areas of different clusters, then a person has to transfer through the hubs.

Travel time(i, j)= Shortest travel time between i and hb_1 + Shortest travel time between hb_1 to hb2 + shortest travel time between hb_2 to j + + waiting time at 'i' + waiting time at hb_1 + waiting time at hb_2

'Passenger Time' for traveling from bus stop i to j is calculated depending upon whether the originating and destination stops lie in the same cluster or in different clusters. 'Total Passenger Time' for the network is also estimated.

Passenger Time (i,j) = Inter_stop_dem(i,j) * Travel Time (i,j)

$$\text{Total Passenger Time} = \sum_i \sum_j Passenger\_Time(i,j)$$

The set of clusters, which provide the minimum 'Total Passenger Time', is treated as the optimum number of clusters/hubs for the entire bus transit network.

The above expressions indicate that the 'Travel Time' between a node pair (i,j) has the following components

- Intra hub in-vehicle time
- Inter hub in-vehicle time
- Waiting times for intra hub routes
- Waiting times for inter hub routes

Intra-hub in-vehicle times are the travel time from stops 'i' (and 'j') to their corresponding hubs. Inter-hub in-vehicle time represents the travel time from hub of stop 'i' to the hub of stop 'j'. In the process of traveling from stop 'i' to stop 'j', the waiting times are also to be considered for intra hub and inter hub routes.

As the number of hubs increases, the size of the clusters/influence area of hubs will decrease thereby reducing the intra hub distances/ in-vehicle times from stops to the hub. With the increase of number of hubs, the inter-hub in-vehicle time will also show a decreasing trend. The reason may be attributed to the fact that increasing the number of clusters will bring the hubs closer and thereby decrease the inter-hub distances/in- vehicle times. But the increase in number of clusters will increase the number of transfers involved and thereby increase the waiting times.

The objective is to determine that optimal number of clusters, which minimize the total passenger time. For a certain set of clusters, both intra hub and inter hub in-vehicle times depend upon the road characteristics. But the waiting times at stops and hubs will depend upon the operating characteristics of the transit system. To test the sensitivity of these parameters, total passenger time is estimated for the following cases:

- Waiting times for inter hub routes: As the inter hub routes will have high frequency of operation, trials are made for two values of 120 and 300 seconds.
- Waiting times for intra hub routes: These routes will have relatively low frequency of operation and trials are made for four different values of 300, 600, 900 and 1200 seconds

The estimated total passenger-time of the transit system is obtained through the Self-organizing map and fuzzy-c-means clustering method and is presented in Tables 6.4 and Table 6.5 respectively for five sets of waiting times and for clusters varying between 25 and 60.

It is observed that for the self-organizing map method, the optimum number of cluster is 50 for four sets of waiting times. Only for one set of waiting times, the optimum number of clusters is 55 though the value of the objective function for 50 clusters is close to the optimum value. The results from fuzzy-c-means clustering method indicate that for all the five sets of waiting times, the minimum values of the objective function occur for 55 and 30 clusters. The passenger-time of the transit system for different number of clusters is shown in Figure 6.2 for self-organizing map and fuzzy-c-means clustering method. These plots are for inter hub waiting time of 120 seconds and intra hub waiting time of 300 seconds.

Based on the results of both methods, a set of 50 clusters is considered for further planning of bus routes. Figure 6.3 shows the location of hub chosen in each cluster for the study area of Delhi. This choice is preliminary and may be fine-tuned based on the facilities available at the selected hubs.

Table 6.4: System-Passenger-Time by Self-organizing Map Clustering Method

	System Passenger-time (millon-seconds)				
Hub-wait-time	120	120	300	300	300
Stop-wait-time / No. of Clusters	300	600	600	900	1200
25	24892.13	28982.38	30056.23	34146.52	38236.91
30	24265.59	28414.75	29523.65	33672.84	37822.39
35	24458.29	28659.33	29799.45	34000.41	38201.51
40	23739.87	28000.35	29176.62	33437.02	37697.99
45	23667.90	27931.98	29109.79	33373.84	37637.99
50	22620.70*	26931.40	28137.39*	32447.98*	36758.79*
55	23056.10	26369.75*	28577.47	32891.33	37204.75
60	23151.75	27512.47	28748.44	33109.37	37470.03

* Optimal values

Table 6.5: System-Passenger-Time by Fuzzy-c-means Clustering Method

	System Passenger-time (millon-seconds)				
Hub-wait-time	120	120	300	300	300
Stop-wait-time / No. of Clusters	300	600	600	900	1200
25	25360.46	29436.97	30502.40	34578.73	38655.73
30	24203.44	28292.54	29365.70	33454.66	37543.64
35	24981.09	29163.36	30292.32	34474.48	38656.58
40	25213.38	29433.27	30584.85	34804.71	39024.66
45	24227.82	28477.98	29647.97	33898.40	38148.88
50	24564.30	28843.22	30030.12	34309.18	38588.35
55	24081.91	28358.76	29543.99	33821.00	38097.62
60	27997.85	32242.54	33409.13	37653.88	41898.84

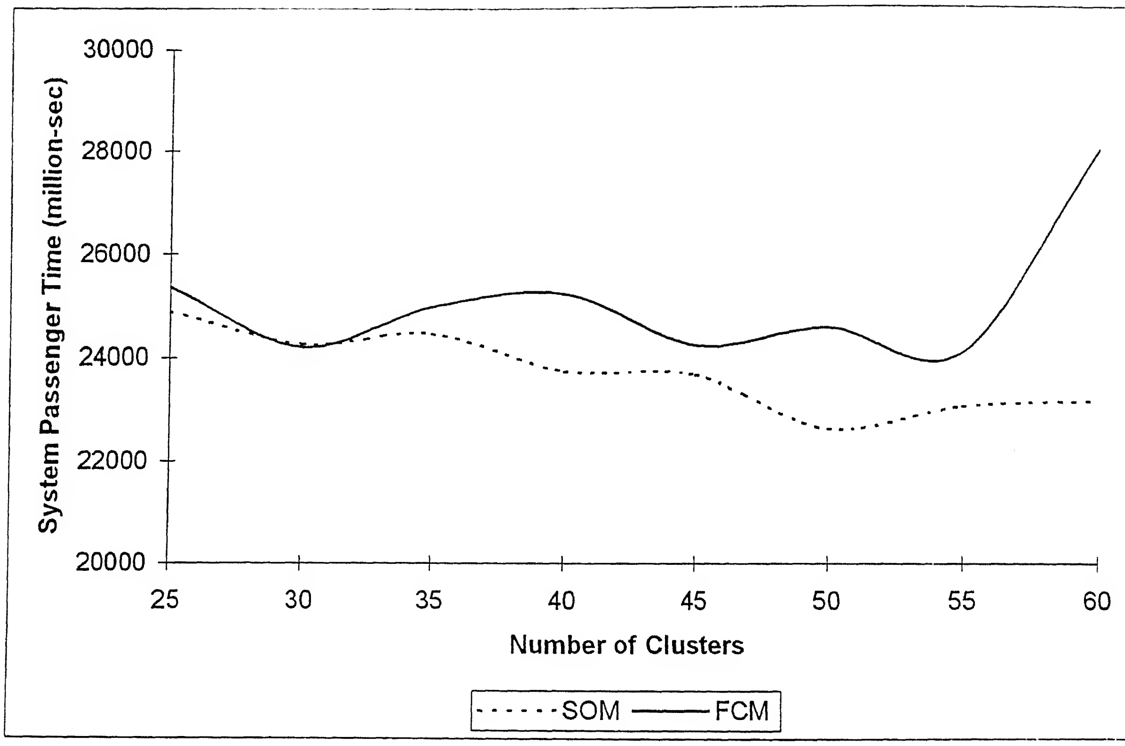


Figure 6.2: System Passenger Time Vs Number of Clusters for SOM and FCM

6.3 ESTIMATION OF DEMAND FOR HUB AND SPOKE BUS TRANSIT NETWORK

Hub and spokes bus transit system consists of two types of routes, inter-hub routes and intra-hub routes (Spoke or Secondary routes). To generate these two types of routes, the inter-stop demand matrix is adjusted to estimate the following two demand matrices.

(i) Inter-hub demand matrix

(ii) Intra-hub demand matrix

The Inter – hub demand matrix represents the estimated demand between the hubs and is of interest in planning inter-hub routes.

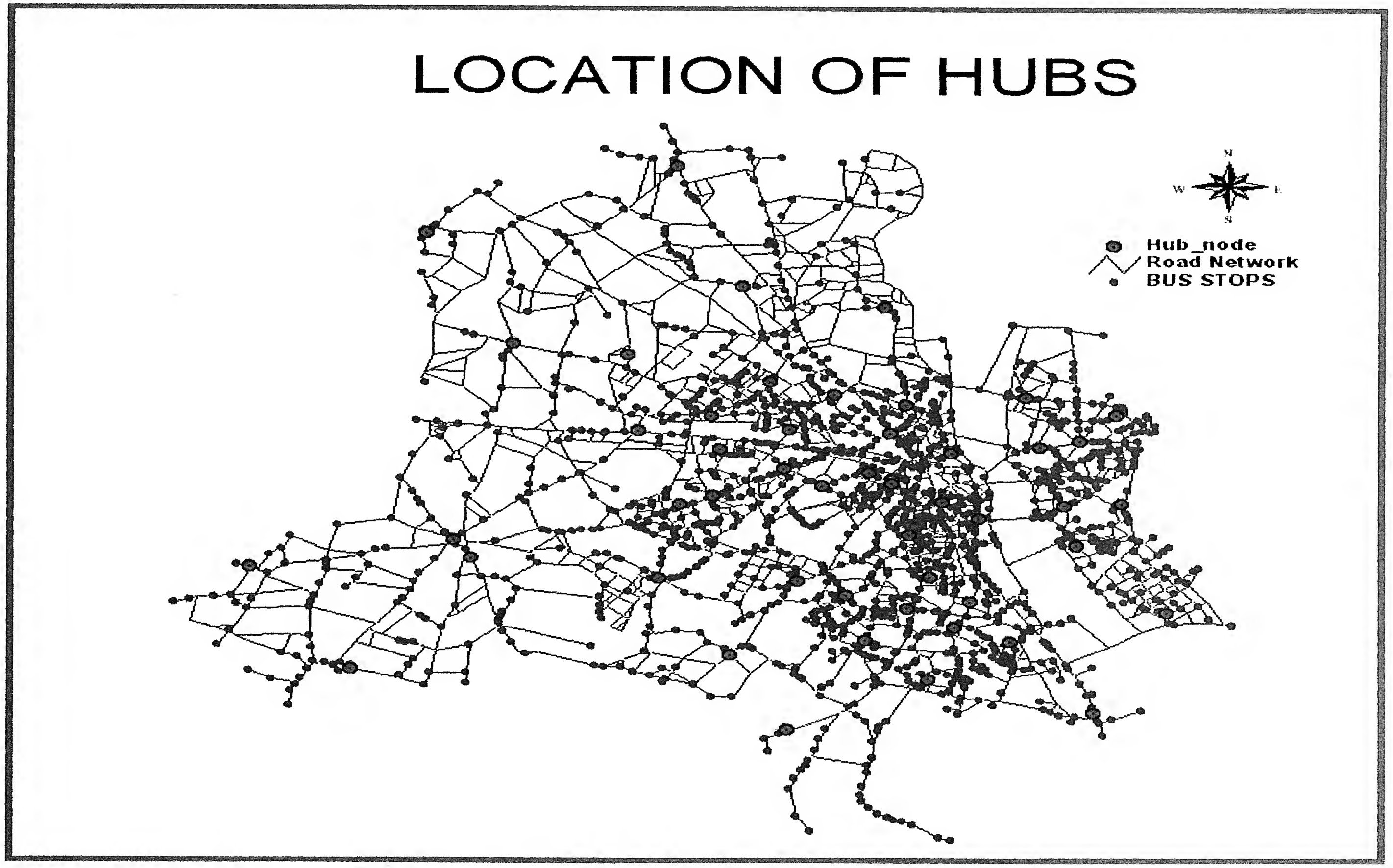


Figure 6.3: Location of Hubs in the Study Area

The intra hub demand matrix consists of demand obtained from two components.

- Feeder demand: The demand of stops lying in the influence area of a particular hub 'hb' and going to the influence area of some other hub.
- Demand between stop to stop within the influence area of a hub 'hb'.

The relations to generate these matrices are presented in the study methodology.

6.4 GENERATION OF INTER HUB ROUTES

The inter hub routes provide connectivity between the hubs and satisfy high demand. These routes are reasonably direct, have high frequency and high operating speed of the buses. If feasible, each hub may be connected to every other hub subject to the constraints of demand and distance. For the 50 identified hubs, this may results into (50*49/2)=1225 routes. But as it may not be feasible to operate on such a large number of generated routes, therefore some operational constraints like minimum inter-hub demand, minimum and maximum route length etc. may be incorporated for the selection of terminal hubs.

The generation of inter-hub routes consists of the following steps.

(i) Identification of terminal hubs

(ii) Generation of alternative paths between terminal hubs

(iii) Evaluation of alternative paths by a predefined criteria

(iv) Selection of optimal path

The terminal hubs are first connected to each other along the shortest path. Meandering along the shortest path generates alternative paths between the two terminal hubs. These alternative paths are evaluated such that the stops/hubs along the generated routes are served in an optimal way. The alternative paths are short-listed using a criterion of 'Route Utilization Coefficient' and the final selection of optimal path is done on the basis of maximum 'Desire-passenger-km per km'.

As an illustration, two terminal stops Kendriya terminal and Nangloi are selected for generating an inter-hub route. Alternative paths are generated between these two

terminals. Thirty-eight paths are generated between the two terminals with a meandering factor of 1.5. Table 6.6 presents the statistics of alternative paths generated between the terminals. Based on the selection-criteria, the alternative thirty fourth is selected as the optimal path.

Table 6.6: Statistics for Alternative Paths Generated between Nangloi and Kendriya Terminal

Alternative Number	Route Length	Satisfied demand	Demand satisfied per km	Passenger-Km	Passenger-Km per Km
1	28300	2053	73	58100	2053
2	40279	3977	99	92422	2295
3	39734	17328	436	270632	6811
4	39651	17328	437	270632	6825
5	41941	3977	95	92422	2204
6	39852	2053	52	58100	1458
7	35092	18899	539	287158	8183
8	35795	18899	528	287158	8022
9	41178	3977	97	92422	2244
10	28742	2053	71	58100	2021
11	34324	18899	551	287158	8366
12	36723	3977	108	92422	2517
13	37204	3977	107	92422	2484
14	30474	18899	620	287158	9423
15	33265	18899	568	287158	8632
16	32788	18899	576	287158	8758
17	30554	2053	67	58100	1902
18	37420	18899	505	287158	7674
19	42307	3977	94	92422	2185
20	41455	18899	456	287158	6927
21	42401	3977	94	92422	2180
22	31632	2053	65	58100	1837
23	29157	2053	70	58100	1993
24	33003	2053	62	58100	1760
25	38770	2053	53	58100	1499
26	41751	2053	49	58100	1392
27	34742	18899	544	287158	8265
28	30782	2053	67	58100	1887
29	32126	2053	64	58100	1809
30	41707	3977	95	92422	2216
31	36816	18899	513	287158	7800
32	39144	2053	52	58100	1484
33	40707	17328	426	270632	6648
34	41757	57906	1387	500825	11994
35	39909	3977	100	92422	2316
36	40012	2053	51	58100	1452
37	35369	18899	534	287158	8119
38	40727	2053	50	58100	142

In Delhi the daily public transport demand is spread over an equivalent period of 11 peak hours. Considering the bus capacity of 50 passengers, if a high frequency route is operated at policy headway of 15 minutes, it will cater to the daily demand of (11*60)*50/15 = 2200 passengers moving between the terminals. Increasing the policy headway to 30 minutes, the daily demand satisfied along the route turns out to 1100 passengers. These observations are taken into considerations for devising the constraints on demand between the terminals. As the limit of daily demand between the terminals is reduced, more number of terminal pairs will be identified, more routes will get generated and higher proportion of the demand matrix will be satisfied. To test the sensitivity of the model to generate routes, the limit of demand is varied from 6600 passengers (corresponding to headway of 5 minutes) to 1000 passengers.

The selections of terminal pair starts with those of highest inter hub demand and with the shortest distance of at least 1 Km. First alternative path considered is the shortest path. Incorporating a meandering factor of 1.25, alternative paths are generated. The alternative paths are short-listed using a criterion of 'Route utilization coefficient' and the final selection of optimal path is done on the basis of maximum 'Desire-passenger-km per Km'. Table 6.7 presents the characteristics of the optimal inter hub routes generated for different levels of demand constraints. For the daily demand constraint of 6600, a total of 88 inter hub optimal routes are selected. The demand satisfied along the paths of these 88 routes is only 85.65 percent of the total desired demand.

Table 6.7: Optimal Inter-hub Routes for different Daily Demand Constraints

S.No	Minimum demand constraint	Inter-hub routes generated	Demand satisfied (percent)	Average route length (km)	Maximum route length (km)
1	6600	88	85.65	13.78	38.9
2	3300	123	93.78	17.76	54.1
3	1500	160	97.91	20.89	54.9
4	1000	181	98.81	21.90	54.9

Since significant proportion (14.35 percent) of daily passenger demand is left out with the generation of 88 inter-hub routes, therefore the limit of daily passenger demand between terminals is reduced. This leads to increase in number of routes and more demand is satisfied. It is observed from the Table 6.7 that for demand limit of 1000, a total of 181 optimal routes are generated and these satisfy 98.81 percent of the total demand.

As the generation of 181 inter-hub routes for hub and spokes system satisfies significant amount (98.81 percent) of total daily passenger demand, therefore these routes are adopted for the system and are further analyzed. The frequency distribution of lengths generated for 181 inter-hub routes is shown in Figure 6.4. The path of these routes is given in the Appendix–B. With this network, only 1.19 percent of inter hub demand is left out. This small proportion is corresponding to a few pairs, which can be satisfied through transfers. The maximum route length from these routes is 54.9 Km and the average route length is 21.90 Km. Table 6.8 presents the number of inter hub routes terminating, the number of routes passing, and the total routes for each of the hub. The total daily production and attraction for the hubs is also given. Maximum daily trip production of 185997 passengers is observed at Minto road Terminal and the maximum number of 45 inter-hub routes serves this hub. A maximum of 17 routes terminate at ISBT. Some hubs, which have low generation, are located in the outskirts of the city, and provide connectivity to villages, have only two routes serving them.

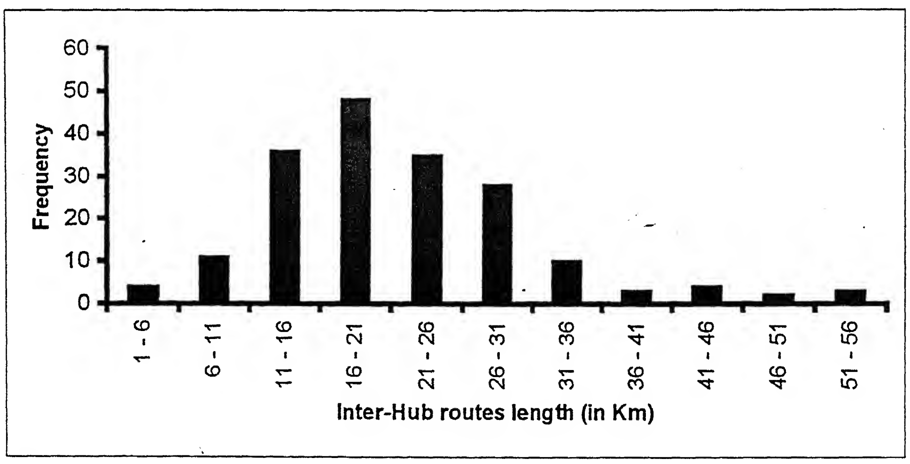


Figure 6.4: Frequency Distribution of Lengths for Inter-Hub Routes

Table 6.8: Details of Routes at Hubs

Hub	Name of Hub	Production	Attraction	Number of		
				Terminating Routes	Passing Routes	Total Routes
6	N Pitam Pura	25517	30261	9	6	15
32	Pasch Vih	15413	16858	10	0	10
61	Shlm Bagh	24231	29258	13	6	19
96	Narela Mandi	10730	11876	8	0	8
192	Kanjhawala	6802	7899	8	2	10
292	Burari Garhi	1156	492	2	0	2
333	Khera Garhi	2223	2091	6	1	7
374	Begum Pur	15390	17942	5	5	10
451	Silam Pur	19640	20977	6	14	20
460	Shahadra	121693	146458	6	14	20
544	Shakhar Pur	16111	18429	3	20	23
545	P.P. Ganj Mor	6113	5709	4	3	7
559	P.P. Ganj	8997	9868	10	2	12
627	Arun Vih Sect 37	64	161	2	0	2
667	Minto Road Trml	185997	266387	7	38	45
724	West Patel Ngr	15849	15784	3	21	24
752	Nehru Place	20906	25573	12	5	17
793	Badar Pur	12680	14952	8	0	8
841	I.I.T. Hostel	12506	15819	10	2	12
887	Mandir Marg	10424	12949	9	6	15
898	Moti Bagh	1764	1730	7	20	27
953	Defence Colony	45799	62258	4	24	28
983	Rang Puri Palam	1040	156	4	0	4
1016	Ghatorni School	6057	5042	5	0	5
1025	Arjun Path	1184	1202	6	0	6
1077	Chappar Wala	14577	14126	8	14	22
1107	Mukherji Park	30365	37690	5	29	34
1142	Roshan Pura	554	99	3	2	5
1181	Bakkar Garh Village	1802	1415	5	0	5
1212	Ghuman Hera	308	203	2	0	2
1285	Palam Village	9038	8984	14	1	15
1363	Bhajanpura	71297	84927	11	1	12
1371	Britania	27516	33022	2	25	27
1383	Dev Ngr	69469	87226	12	7	19
1398	Faiz Rd DBG RD	74017	92863	3	29	32
1412	ITO Vikas Marg	28018	25884	14	25	39
1413	ISBT (NN Marg)	44700	44139	17	10	27
1438	Kendriya Trm	22466	27044	7	14	21
1443	Safdarjung hospital	24939	30581	8	23	31
1460	Moti Ngr Mor	49237	64178	5	27	32
1469	Najaf Garh	7450	10680	5	1	6
1470	Nangloi	32343	41145	7	5	12
1471	Nand Nagri	33395	38204	10	2	12
1482	Qutab Garh	12060	14662	8	1	9
1484	Kingsway Camp	26050	30732	11	11	22
1504	Central School	12753	12577	5	8	13
1506	Shakti Ngr	22592	27072	8	11	19
1508	Tilak Ngr	81360	109011	10	13	23
1520	Pushpanjali	14142	15563	5	14	19
1533	Jor Bagh	54352	74363	10	5	15

6.5 SCHEDULING OF INTER-HUB ROUTES

A bus transit network consists of a large number of inter-hub routes overlapping each other on a number of links. Scheduling allocates the buses optimally among these overlapping routes. The iterative heuristic algorithm developed in the study methodology schedules the bus trips for peak period and off-peak periods. This algorithm has the following steps.

(i) Estimation of passenger flow on each link
(ii) Determination of desired trips for each link
(iii) Assignment of minimum trips for each route
(iv) Estimation of additional trips on each route
(v) Revised trips on each route of transit network.

The bus trips to be operated for a route depends upon the demand served along the route and the passenger flow on various links of the route. As more than one route may share some inter-nodal demand, the iterative heuristic algorithm starts with estimation of passenger flow on each link. Each OD pair of the transit network through shortest path is considered and the total demand matrix is loaded on the transit network. The desired bus trips for each link of the transit network are determined at different level of services. The minimum bus trips, which can be assigned to each route, are determined. The additional bus trips on links due to the overlapping of routes are estimated. The estimated proportional bus trips on a route are determined for each link of the route path. The minimum of these trips is considered as the additional trips for the route.

The revised bus trips for each of the overlapping routes moving on the link are determined as the sum of already assigned trips and the additional bus trips for the route. This iterative process is continued till no more additional bus trips are required on each route. Round trip time for each route is calculated and the desired headway of operation for each route is estimated. Fleet size required for the period of scheduling is determined and various characteristics of the scheduling plan for the system are worked out.

The limits of headway for inter-bus routes adopted in this study are specified in Table 6.9. The limit of maximum headway determines the minimum number of bus trips, while the minimum headway is based on the operational constraints.

Table 6.9: Limits of Time Headways for Inter-hub Routes

Period	Minimum Headway (Minutes)	Maximum Headway (Minutes)
Peak period	0.5	10
Mid-day period	0.5	15

Level of service is defined in terms of desired average bus load along the route. Four different levels of service (LOS-I to IV) are taken up in scheduling the inter-hub routes and are given in Table 6.10.

Table 6.10: Level of Services for Inter-hub Routes

Level of Service	Desired average bus load
LOS-I	35
LOS-II	40
LOS-III	45
LOS-IV	50

In the metropolitan city of New Delhi, the scheduling of buses is made for various periods of the day i.e peak and mid-day period. It is observed that each of the two peak periods of three-hour duration account for 25 percent of the daily demand. The mid-day period of six-hour duration accounts for 31 percent of the daily demand.

6.5.1 Scheduling Characteristics of Inter-hub Routes (Peak-period)

Scheduled time headways of operation for the 181 routes range between 0.6 to 20 minutes for the peak period of 3-hour duration. Maximum of 299 bus trips are required to operate at minimum headway of 0.6 minutes in each direction, whereas 18 bus trips are required at headway of 10 minutes. Number of buses required for the routes to operate

the scheduled trips range between 5 and 355 for the highest level of service (LOS-I). Parking lots required at the hubs to operate the scheduled trips of different routes vary between 1 and 6.

Table 6.11 presents the systems operating characteristics for peak period of inter-hub routes. A fleet of 9943 buses is required for 181 inter-hub routes to be operated at first level of service (LOS-I). For a peak period of 3 hours, on an average each bus is operated for 51 Km. The total passenger demand of 1117363 passengers during 3-hour duration of peak period is to be satisfied by 181 inter-hub routes. As the level of service decreases, the fleet size required for all the 181 routes decreases and the total passenger waiting time increases. A fleet of 9943 buses at LOS-I decreases to 8786 buses at LOS-II, which further reduces to 7904 buses at LOS-III. The minimum fleet size of 7203 buses is required at LOS-IV. The total passenger waiting time increases from 26700 hours at LOS-I to 36730 hours at LOS-IV, an increase of 37.6 percent. The average waiting time increases from 1.4 minutes to 2.0 minutes, as the LOS-I decreases to LOS-IV.

Table 6.11: System Operating Characteristics of Inter-hub Routes (Peak period)

Period pass. Demand for inter-hub routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
1117363	I	9943	511146	51	6.86	26700	1.4	34	49
	II	8786	452367	51	6.07	30202	1.6	38	55
	III	7904	406941	51	5.46	33571	1.8	43	62
	IV	7203	371712	52	4.99	36730	2.0	47	68

6.5.2 Scheduling Characteristics of Inter-hub Routes (Mid-day period)

Table 6.12 presents the systems operating characteristics for Mid-day period of inter-hub routes. Scheduled time headways of operation for the 181 inter-hub routes range between

0.97 minutes to 15 minutes for mid day period of 6-hour duration. Maximum of 370 bus trips are required to operate at headway of 0.97 minutes in each direction, whereas 24 bus trips are required at headway of 15 minutes. For the highest level of service (LOS-I), number of buses required to operate the scheduled trips range from 4 to 220. A fleet of 6148 buses is required for 181 inter-hub routes to be operated at first level of service (LOS-I). For this mid-day period of 6 hours, on an average each bus is operated for 103 Km.

The total passenger demand of 1385530 passengers for 6-hour duration is to be satisfied through 181 inter-hub routes. As the level of service decreases, the fleet size required for all the 181 routes decreases and the total passenger waiting time increases. A fleet of 6148 buses at LOS-I decreases to 5438 buses at LOS-II, which further reduces to 4892 buses at LOS-III. The minimum fleet size of 4460 buses is required at LOS-IV. The total waiting passenger time increases from 53576 hours at LOS-I to 73533 hours at LOS-IV, an increase of 37.2 percent. The average waiting time increases from 2.3 minutes to 3.2 minutes, as the LOS-I decreases to LOS-IV.

Table 6.12: System Operating Characteristics of Inter-hub Routes (Mid-day period)

Period pass. Demand for inter-hub routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
1385530	I	6148	632005	103	6.84	53576	2.3	34	49
	II	5438	559235	103	6.05	60572	2.6	38	56
	III	4892	503747	103	5.45	67243	2.9	43	62
	IV	4460	460157	103	4.98	73533	3.2	47	68

6.5.3 Scheduling Characteristics for the Inter-hub Routes System

It is observed from the results that for peak period, a total fleet of 9943 buses is required at the desired level (LOS-I). For the level of service LOS-IV, the required fleet size is only 7203 but it provides a poor level of service, average and maximum bus loads being 41 and 59 respectively. During off peak period (11 A.M. to 5 P.M.), the fleet size required for the LOS-I, is only 6148 buses. The total fleet size to be commissioned will be based on the requirement for the peak period. During the peak period of 3 hours, the buses operate on an average about 51 km, while for the mid day period of 6 hours, the average operating distance is of the order of 103 km. The average passenger waiting time for the best level of service (LOS-I) is 1.4 minutes for the peak period and 2.3 minutes for off peak period. This passenger waiting time increases with the deterioration of the level of service, being 2.0 minutes for the peak period and 3.2 minutes for the mid day period at the worst level of service (LOS-IV).

The total operating cost for the bus system is determined considering an operation cost of Rs. 15 per Km. The operation cost per passenger is estimated and found to be Rs 6.86 for LOS-I and Rs 4.99 for LOS-IV. The bus operation cost for each passenger is found to be Rs 6.84 for the Mid-day period at LOS-I and Rs. 4.98 for LOS-IV.

6.6 GENERATION OF SECONDARY ROUTES

Secondary routes are generated within the influence area of each Hub to facilitate the trip-makers for reaching the hub or to execute the journey within the influence area of hub. Majority of these routes feed the hubs to enable the commuters to move through inter-hub routes for long distance journeys. One end of these routes is an already established hub and the second terminal with considerable demand and satisfying the properties of a good terminal at the farthest end within the influence area of hub is identified. Shortest distance path is generated between the hub and identified terminal or between the two identified terminals. Alternative paths are generated between the terminals subject to no backtracking. An alternative that maximizes the 'Desire-Passenger-km per km' is adopted as the optimal secondary path. The procedure is repeated till all stops in the influence area are considered and optimally generated routes

within the influence area for a particular hub is obtained. A total of 305 secondary routes are generated for all the fifty hubs and their paths are presented in Appendix-C. Table 6.13 presents the number of routes generated and their characteristics at each hub. Comparison of route lengths in a hub is presented through maximum, minimum and average of secondary route lengths. The number of routes in a hub depends upon the size and shape of the influence area. Highest number of 15 secondary routes is generated within the influence area of Arun Vihar hub, while some hubs have only1-2 routes. Six hubs, lying primarily on the outskirts of the city and with large influence area, have routes longer than 10 Km. The maximum length of 23.1 km for a secondary route is observed for Narela Mandi hub. The average length of secondary routes for all the hubs is generally within 10 Km.

6.7 SCHEDULING OF SECONDARY ROUTES

To allocate the buses optimally to the generated secondary routes of Hubs, the heuristic algorithm developed in study methodology schedules the bus trips for peak period and off-peak period of the day. The link nearest to the hub will have maximum link flow and link touching the terminal will have minimum link flow. The maximum passenger link flow and weighted average link flow along the path are estimated. The maximum bus load and average bus load for various levels of service under consideration are assigned to estimate the bus trips. Desired headway of operation on the route and the number of buses required for the period of scheduling is determined.

The generated secondary routes are to be operated at certain minimum and maximum policy headway during peak-period and off-peak period. The limits of headway for secondary routes adopted in this analysis are given in Table 6.14.

Four different Levels of service (LOS I – LOS IV) are identified for scheduling and operational bus loads are presented in Table 6.15.

Table 6.13: Characteristics of Secondary Routes

Hub code	Name of Hub	No. of sec. routes	Max. length	Min. length	Av. Length
6	N Pitam Pura	6	5.9	3.7	4.9
32	Pasch Vih	3	3.7	2.3	3.0
61	Shlm Bagh	7	5.3	3.3	4.2
96	Narela Mandi	7	23.1	3.2	10.2
192	Kanjhawala	7	8.9	5.4	7.0
292	Burari Garhi	2	6.7	5.0	5.8
333	Khera Garhi	10	19.4	2.5	11.3
374	Begum Pur	4	9.0	7.8	8.5
451	Silam Pur	4	5.1	3.7	4.5
460	Shahadra	14	6.9	3.4	5.3
544	Shakhar Pur	7	4.3	2.7	3.4
545	P.P. Ganj Mor	2	5.2	2.8	4.0
559	P.P. Ganj	6	4.7	2.5	3.2
627	Arun Vih Sect 37	15	6.8	2.3	4.1
667	Minto Road Trml	6	2.7	1.1	2.0
724	West Patel Ngr	6	5.5	2.9	4.2
752	Nehru Place	14	7.5	2.4	4.5
793	Badar Pur	6	7.9	2.2	4.9
841	I.I.T. Hostel	10	9.6	2.2	5.8
887	Mandir Marg	10	11.3	3.1	6.6
898	Moti Bagh	7	5.7	2.3	4.2
953	Defence Colony	9	4.4	2.5	3.4
983	Rang Puri Palam	9	7.7	4.3	5.8
1016	Ghatorni School	3	15.9	2.4	10.4
1025	Arjun Path	8	5.0	3.2	4.1
1077	Chappar Wala	3	5.4	2.3	3.6
1107	Mukherji Park	5	6.2	3.6	4.8
1142	Roshan Pura	7	9.3	2.4	6.2
1181	Bakkar Garh Village	11	8.7	3.2	5.7
1212	Ghuman Hera	7	8.5	4.9	6.4
1285	Palam Village	9	19.9	2.5	6.8
1363	Bhajanpura	6	8.7	3.8	6.4
1371	Britania	1	2.3	2.3	2.3
1383	Dev Ngr	3	5.1	3.1	3.9
1398	Faiz Rd DBG RD	1	2.7	2.7	2.7
1412	ITO Vikas Marg	7	3.3	2.5	2.9
1413	ISBT (NN Marg)	3	6.3	2.5	4.8
1438	Kendriya Trm	4	3.5	2.4	2.9
1443	Safdarjung hospital	-	-	-	-
1460	Moti Ngr Mor	1	2.9	2.9	2.9
1469	Najaf Garh	8	10.9	4.1	7.4
1470	Nangloi	6	9.7	2.6	5.2
1471	Nand Nagri	9	6.8	2.9	4.3
1482	Qutab Garh	4	9.8	5.6	7.8
1484	Kingsway Camp	4	7.4	2.5	4.3
1504	Central School	3	5.4	2.7	4.2
1506	Shakti Ngr	2	3.4	3.0	3.2
1508	Tilak Ngr	11	9.6	2.3	4.7
1520	Pushpanjali	5	4.6	2.4	3.1
1533	Jor Bagh	3	4.4	2.6	3.2

Table 6.14: Limits of Time Headways for Secondary Routes

Period	Minimum Headway (Minutes)	Maximum Headw (Minutes)
Peak period	3.0	15
Mid-day period	3.0	20

Table 6.15: Level of Service for Scheduling Plan of Secondary

Level of Service	Minimum bus load	Maximum bus
I	35	60-70
II	40	65-75
III	45	70-80
IV	50	75-85

6.7.1 Scheduling Characteristics of Secondary Routes (Peak-period)

The scheduled time headways for the 305 generated secondary routes in 50 h between 3 to 15 minutes, with the bus trips in each direction between 12 and peak period of three-hour duration. Number of buses required for the routes to o scheduled trips range between 2 and 31.

Table 6.16 presents the systems operating characteristics for peak period of secondary routes. The generated 305 secondary routes require a fleet size of 1554 buses for LOS-I. For the peak period of 3 hours, on an average each bus is operated for 44 Km. The total passenger demand of 412631 passengers during 3-hour duration of peak period is to be satisfied by 305 secondary routes. As the level of service decreases, the fleet size required for all the 305 routes decreases and the total passenger waiting time increases. A fleet of 1554 buses at LOS-I decreases to 1497 buses at LOS-II, which further reduces to 1456 buses at LOS-III. The minimum fleet size of 1428 buses is required at LOS-IV. The total waiting passenger time increases from 14433 hours at LOS-I to 16283 hours at LOS-IV,

an increase of 11.4 percent. The average waiting time increases from 2.1 minutes to 2.4 minutes, as the LOS-I decreases to LOS-IV.

Table 6.16: System Operating Characteristics of Secondary Routes (Peak period)

Period pass. Demand for Secondary routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
412631	I	1554	69036	44	2.51	14433	2.1	45	60
	II	1497	66412	44	2.41	15129	2.2	46	63
	III	1456	64780	44	2.36	15719	2.3	48	65
	IV	1428	63245	44	2.30	16283	2.4	49	66

The various scheduling parameters for the secondary routes are aggregated for each hub to determine the operating characteristics and is presented in Table 6.17. A Maximum of 260100 Daily passenger demand is satisfied through the secondary routes at Tilak Nagar hub and the highest number of 121 buses is required to serve the demand.

6.7.2 Scheduling Characteristics for the Secondary Routes (Mid-day period)

The scheduled time headways for the 305 generated secondary routes in 50 hubs range between 3 to 20 minutes for off-peak period of 6-hour duration. Maximum of 120 bus trips are required to operate at minimum headway of 3 minutes in each direction, whereas 18 bus trips are required at headway of 20 minutes. For the highest level of service (LOS-I), number of buses required to operate the scheduled trips for different routes range from 2 to 31.

Table 6.18 presents the systems operating characteristics for Mid-day period of secondary routes. A fleet of 1460 buses is required for 305 secondary routes to be operated at first level of service (LOS-I). For an off-peak period of 6 hours, on an average each bus is operated for 91 Km.

Table 6.17: Characteristics of Secondary Routes on Hub Terminals (Peak-period)

Hub Terminal	Daily passenger demand at hub	No of feeder routes	Level of service					
			LOS – I		LOS - II		LOS – III	
			Buses	Park-ing lots	Buses	Park-ing lots	Buses	Park-ing lots
N Pitam Pura	48000	6	22	7	22	7	21	7
Pasch Vih	300	3	6	3	6	3	6	3
Shlm Bagh	29000	7	37	9	31	9	28	9
Narela Mandi	19400	7	32	8	32	8	31	8
Kanjhawala	24200	7	25	8	25	8	25	8
Khera Garhi	3700	10	32	10	31	10	30	10
Begum Pur	18800	4	33	6	33	6	33	6
Silam Pur	68500	4	47	7	47	7	47	7
Shahadra	7800	14	41	14	41	14	40	14
Shakhar Pur	42300	7	39	9	39	9	39	9
P.P. Ganj Mor	16800	2	12	3	12	3	12	3
P.P. Ganj	17200	6	23	8	22	8	19	6
Minto Road Trml	17400	6	29	7	27	7	25	7
West Patel Ngr	200	6	15	6	15	6	15	6
Nehru Place	52300	14	83	19	72	19	67	19
Badar Pur	4700	6	16	7	16	7	16	6
I.I.T. Hostel	21800	10	38	11	38	11	36	11
Mandir Marg	69800	10	61	13	56	12	53	12
Moti Bagh	21800	7	23	8	22	8	18	8
Defence Colony	80000	9	52	13	51	13	51	13
Ghatorni School	1000	3	9	3	9	3	9	3
Chappar Wala	26600	3	31	4	30	4	28	4
Mukherji Park	78800	5	46	8	46	8	46	8
Palam Village	44800	9	56	11	56	11	56	11
Bhajanpura	40700	6	52	9	49	9	49	9
Britania	79700	1	7	2	7	2	7	2
Dev Ngr	39400	3	33	5	33	5	33	5
Faiz Rd DBG RD	6900	1	9	2	9	2	9	2
ITO Vikas Marg	7900	7	20	7	20	7	18	7
ISBT (NN Marg)	31800	3	58	5	43	5	43	5
Moti Ngr Mor	13900	1	10	2	10	2	10	2
Najaf Garh	3200	8	19	8	19	8	19	8
Nangloi	38000	6	30	9	29	9	29	9
Nand Nagri	92200	9	105	18	101	17	96	16
Qutab Garh	47400	4	40	7	38	7	36	7
Kingsway Camp	110800	4	28	5	27	5	27	5
Central School	28400	3	16	4	16	4	16	4
Shakti Ngr	8000	2	14	3	13	3	13	3
Tilak Ngr	260100	11	121	20	121	20	118	20
Pushpanjali	97700	5	35	9	35	9	35	9
Jor Bagh	29000	3	23	6	22	6	21	6

The total passenger demand of 511662 passengers during 6-hour duration of off-peak period is to be satisfied by 305 secondary routes. As the level of service decreases, the fleet size required for all the 305 routes decreases and the total passenger waiting time increases. A fleet of 1460 buses at LOS-I decreases to 1411 buses at LOS-II, which further reduces to 1367 buses at LOS-III. The minimum fleet size of 1334 buses is required at LOS-IV. The total waiting passenger time increases from 20889 hours at LOS-I to 23891 hours at LOS-IV, an increase of 12.6 percent. The average waiting time increases from 2.5 minutes to 2.8 minutes, as the LOS-I decreases to LOS-IV.

Table 6.18: System operating Characteristics of Secondary Routes (Mid-day period)

Period pass. Demand for Secondary routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
511662	I	1460	132942	91	3.90	20889	2.5	29	40
	II	1411	128572	91	3.77	21986	2.6	30	41
	III	1367	125008	91	3.67	22967	2.7	31	43
	IV	1334	121524	91	3.56	23891	2.8	32	44

6.7.3 Scheduling Characteristics for the Secondary Routes System

It is observed from the results that for peak period, a total fleet of 1554 buses is required at the desired level (LOS-I). For the level of service LOS-IV, the required fleet size is only 1428 but it provides a poor level of service, average and maximum bus loads being 49 and 66 respectively. During Mid-day period (11 A.M. to 5 P.M.), the fleet size required for the LOS-I, is only 1460 buses. The total fleet size to be commissioned will be based on the requirement for the peak period. During the peak period of 3 hours, the buses operate on an average about 44 km, while for the mid day period of 6 hours, the average operating distance is of the order of 91 km. The average passenger waiting time for the best level of service (LOS-I) is 2.1 minutes for the peak period and 2.5 minutes for mid day period. This passenger waiting time increases with the deterioration of the

level of service, being 2.4 minutes for the peak period and 2.8 minutes for the mid day period at the worst level of service (LOS-IV).

The total operating cost for the bus system is determined considering an operation cost of Rs. 15 per Km. The operation cost per passenger is estimated and found to be Rs 2.51 for LOS-I and Rs 2.30 for LOS-IV. The bus operation cost for each passenger is found to be higher for the mid day period being Rs 3.90 at LOS-I and Rs. 3.56 for LOS-IV.

6.8 SCHEDULING CHARACTERISTICS OF BUS TRANSIT NETWORK

The study area of New Delhi is served through a total of 486 bus routes with hub and spokes bus transit system approach. The scheduling characteristics of Bus transit network are presented in Table 6.19.

181 inter-hub routes generated satisfy a daily demand of 4469452 passengers, whereas secondary routes cater to a daily demand of 1650524. The total daily demand satisfied through 486 routes turns out to be 6119976. Fleet size required to operate on 181 inter-hub routes is 9943 at LOS-I, which decreases to 7204 at LOS-IV. For secondary routes, the fleet size required to operate on 305 routes is 1554 at LOS-I. The total fleet size required to operate the 486 routes turns out to be 11497 at LOS-I, which gradually decreases to 8631 at LOS-IV. For the inter-hub routes, a bus operates for 239 Km per day and for secondary routes the km per bus per day turns out to be 208. For the total bus transit system a bus operates 234 Km per day. The average waiting time for the bus system during the peak-period varies from 1.6 minutes to 2.1 minutes and for the mid-day period, the average waiting time varies from 2.4 minutes at LOS-I to 3.0 minutes at LOS-IV. For the peak period, the operation cost for the bus system varies from Rs.3.91 at LOS-IV to Rs.5.69 at LOS-I, whereas for the mid-day period, the operation cost varies from Rs.4.60 at LOS-IV to Rs.6.04 at LOS-I.

Table 6.19: Scheduling Characteristics of Bus Transit System

	No. of routes	Daily Demand Satisfied	Level of service	Fleet size	Km per bus per day	Av. Waiting time (Min)		Operation cost per passenger (Rupees)	
						Peak period	Mid day period	Peak period	Mid day period
Inter Hub Routes	181	4469452	I	9943	239	1.4	2.3	6.86	6.84
			II	8786	239	1.6	2.6	6.07	6.05
			III	7904	239	1.8	2.9	5.46	5.45
			IV	7203	239	2.0	3.2	4.99	4.98
Intra Hub Routes	305	1650524	I	1554	208	2.1	2.5	2.51	3.90
			II	1497	208	2.2	2.6	2.41	3.77
			III	1456	208	2.3	2.7	2.36	3.67
			IV	1428	208	2.4	2.8	2.30	3.56
Total Routes	486	6119976	I	11497	234	1.6	2.4	5.69	6.04
			II	10283	234	1.8	2.6	5.08	5.43
			II	9360	234	1.9	2.8	4.62	4.97
			IV	8631	234	2.1	3.0	3.91	4.60

6.9 SUMMARY

In this chapter, the models developed for bus transit network in chapter 3 are applied to Delhi. The model for selection of optimal number of hubs resulted into 50 hubs. 181 inter-hub routes generated by considering constraints on minimum demand and length satisfies significant amount (98.81 percent) of total daily passenger demand. The maximum route length from inter-hub routes is 54.9 Km and the average route length is 21.90 Km. 305 secondary routes are generated for all the 50 hubs. The already existing over 1100 bus routes for Delhi get reduced to 486 routes through hub and spokes bus transit network. For peak period, a total fleet of 9943 buses for inter-hub routes and 1554 buses for secondary routes, thereby a total of 10283 buses are required at the desired level (LOS-I). For the bus transit system a bus operates 234 Km per day.

CHAPTER – 7

FEEDER BUS NETWORK FOR DELHI MASS RAPID TRANSIT SYSTEM

7.1 INTRODUCTION

Introduction of high capacity rapid transit system in a metropolitan city changes the behavior pattern of the trip makers to a large extent. Commuters using the services of slow and chaotic bus transit system can have the flexibility of a fast and efficient integrated transport system. Implementation of such a system will force the restructuring of existing bus network, and provide feeder bus services for effective integration of the two modes. Planning of feeder bus transit system to integrate with Mass rapid transit system (MRTS) necessitates delineation of influence area for MRTS stations and the estimation of demand, which will shift to MRTS. Feeder routes are to be generated within the influence area of the MRTS stations and scheduling plan is to be prepared for these generated routes. Decision support system to integrate high capacity transit system with feeder public transport system therefore, needs a series a heuristic optimization models. In this chapter, the optimization models developed in the chapter of study methodology for feeder public transport system have been effectively implemented for New Delhi, the capital city of India.

7.2 PREPARATION OF DATA BASE

The generation of comprehensive database is a pre-requisite for the successful execution of the study. The database relates to:

- Delineation of study area into zones and characteristics for each zone.
- Inventory of road network characteristics and mapping of road network
- Characteristics of existing bus transit system
- Characteristics of the MRTS corridors.
- Travel demand pattern for public transport

The related database is obtained from Rail India Technical and Economical Services (Reference: Route Rationalization and Time Table Formulation Study for Bus System of Delhi, March 1998 & Planning of Feeder Public Transport System for Phase-I of Delhi MRTS, August 2001, RITES), New Delhi. These are generated through primary surveys and data collected through secondary sources. The capital city area has been delineated into 192 zones, 177 of which are internal and the rest are external zones. A complete inventory of road and traffic characteristics of the network is also obtained. Based on the survey data various nodes and links of the transit network are identified.

For the computational analysis, it is necessary that each bus stop, road junction and MRTS station are to be represented through a mathematical coding system. The following coding pattern is adopted for the road network and MRTS.

Coding of Road Network

The bus stops is represented through 1 onwards up to the total number of bus stops (NB). The range adopted for bus stops in the work varies from 1 to 2500. The coding of road junction points starts from (NB +1) onwards. The range adopted for road junction points is 2501 – 5000. When a bus stop is close to an intersection, maybe within 100 m, the two may be assigned the same code. To have a proper graphical representation of road alignment, dummy nodes have been introduced in the system; where-ever there is a bend in the road link.

Coding of MRTS stations

The MRTS Stations and dummy nodes on MRTS corridor have been given codes ranging from 5001 – 6000. The dummy nodes are introduced between MRTS stations whenever there is a bend in the alignment.

A total of 1542 bus stops, covering a road length of 1650 Km and 2080 road intersections were selected to describe the study area network. Link travel time and the link speed for all links of the network were obtained from the observed bus journey time surveys. The nodal level link list consisting of node from, node to, link length and link speed was thus obtained. The speeds on these links vary from 15 kmph to 30 kmph. Mapping of the existing bus route network on Delhi's map is a gigantic task. State transport authority (STA) and Delhi Transport Corporation (DTC) is operating 1163 routes on the roads of study area. Each route has on an average 15-20 en-route bus stops.

Two MRTS corridors (Figure 7.1) to be introduced in the first phase of implementation are:

- Shadara to Barwala and
- Vishwa-Vidyalaya to Central-Secretariat.

The first corridor from Shadara to Barwala consists of 21 stations and its length is 22 Km. The second corridor with a length of 11 km is totally underground and involves 10 stations. The location of MRTS with respect to existing road network is shown in Figure 7.2. The operating speed on these corridors is taken as 40 Kmph.

Daily Travel demand for the planning of feeder public transport system requires the demand matrix at the bus stop level. The zonal travel demand matrix for the year 1994 obtained from household surveys was extrapolated to obtain zonal demand matrix for the year 2000 using the growth factor method. To convert the zonal demand matrix into bus stop wise demand, the number of bus stops falling in a zone are identified and the weights are assigned to these stops based on their observed traffic generation potential in the total trip generation of the zone. Using the traffic generation potential of bus stops, the zonal demand matrix was converted into inter- bus stop demand matrix. This daily demand matrix of (1542x1542) size represents total demand of 7.67 million passengers for the year 2000.

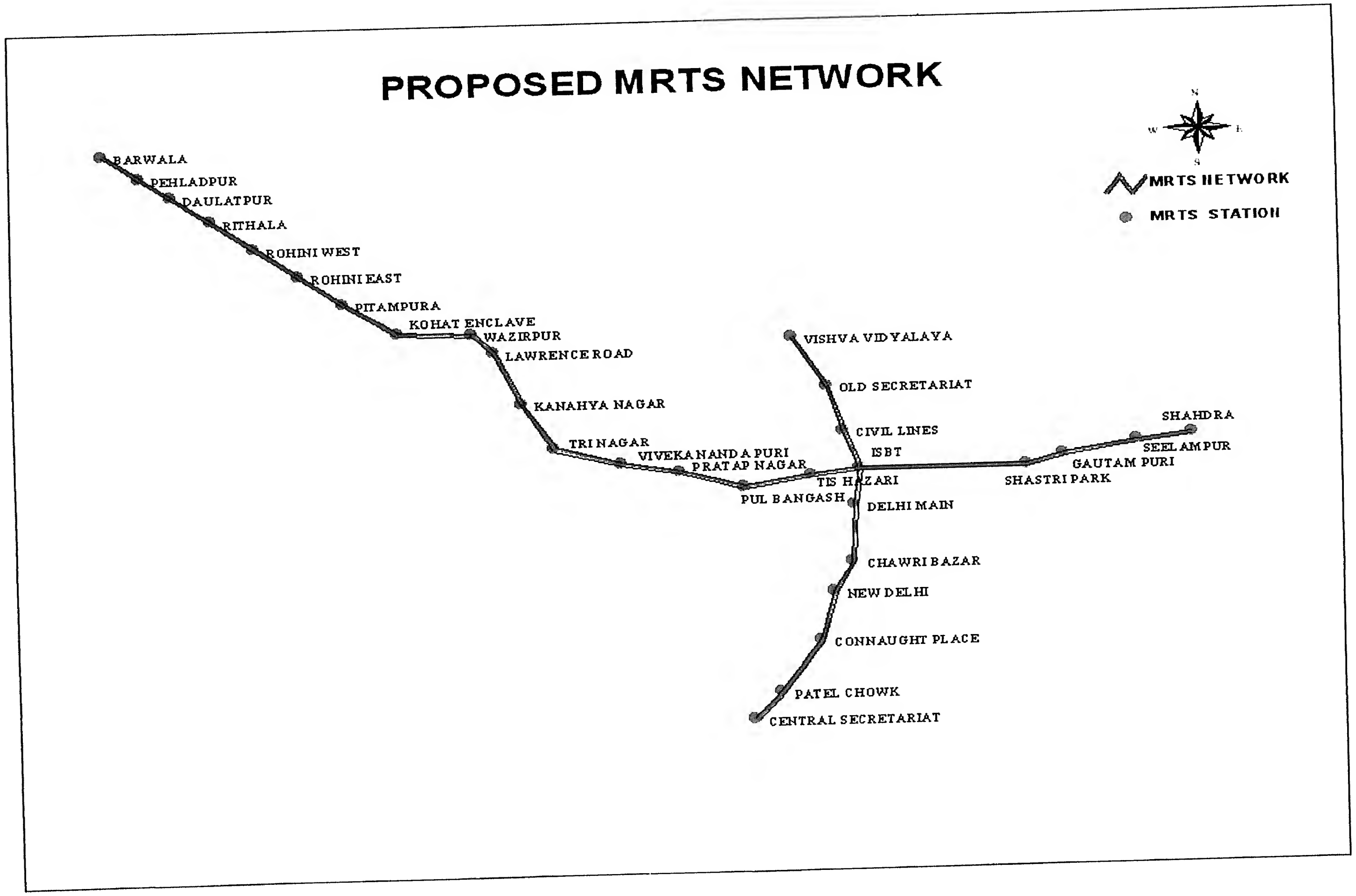


Figure 7.1: Proposed Corridors of Delhi MRTS in Phase - I

Figure 7.2: Location of MRTS with respect to Existing Road Network

7.3 APPLICATION OF MODE CHOICE MODEL

Introduction of high capacity fast mode of transportation in Delhi will attract the commuters from the existing public transport modes. The major portion of demand attracted to MRTS shall be from the existing bus transport system. Mode choice analysis for each O-D pair is carried out to estimate the proportion of demand shifted from existing bus system to MRTS. Logit model as discussed in methodology has been applied to distribute the demand between the two modes of public transport.

The formulated Logit model makes use of the utility measures for the two modes. The utility measures include the bias coefficient and coefficients of parameters, like travel time, travel cost, comfort and transfer penalty for these two modes. To evaluate the utility measures, the coefficients related to these parameters needs to be calibrated. Some calibration has already been done by RITES based on a preference survey on a sample of about 5000 travelers. The data was collected in addition to the primary data stating preference responses and the calibrated coefficients are given in Table 7.1.

Table 7.1: Mode Choice Coefficients obtained from Preference Responses

S.No	Attribute	Non-Vehicle owning household
1.	Time coefficients	0.04711
2.	Cost coefficients	1.024
3.	Bus Bias	-
4.	Rail Bias	4.05760
5.	Value of Time, Rs/Hour	- 2.76

Source: Identification of commuter rail network in NCR region, 1999, RITES, New Delhi.

d based on the data from trip makers when
fficult to suggest a bias coefficient at that
cted to area, and this may not represent the

characteristics of the whole city. For the metropolitan city of Delhi, the share of public and private transport mode data is available and 62 percent of the travelers move through public transport. In this work, the study is restricted to only two parameters of travel time and travel cost, because the realistic data can be available only for these two parameters. Analysis was done with the estimated coefficients for different trip lengths and trip cost between public and private mode. Knowing the number of travelers for different trip lengths, the total share of public transport system is estimated. This analysis helped to calibrate the coefficients of travel time and travel cost. The coefficients obtained for the Logit parameters are shown in Table 7.2. These estimated coefficients are adopted for mode choice analysis between bus and MRTS system.

Table 7.2: Coefficients of Logit Parameters for Utility Measures

S.No.	Logit Parameters of utility measure	Coefficients of parameters
1.	Travel Time coefficient	-0.001
2.	Travel cost coefficient	-0.026

The mode choice analysis between any OD pair involves the estimation of following parameters.

(i) In vehicle travel time from Origin to Destination.

(ii) Transfer time at MRTS stations.

(iii) Waiting time on the bus and MRTS system.

(iv) Travel cost through bus and MRTS/feeder system.

Travel time between any OD pair through bus routes can be estimated through zero transfer, one-transfer or two transfer routes as explained earlier in the study methodology. Similarly, the travel time through the combination of MRTS and feeder bus routes can be estimated as elaborated in study methodology. The travel cost for traveling through bus system or a combination of MRTS and feeder bus system can be taken up either in unit rate per kilometer or slab rate. Planning of feeder routes can be at one or both ends of the trip. Combination of the fare system and availability to one/two end feeder service leads to eight options.

These parameters along with the calibrated coefficients help to estimate the proportion of trip makers by MRTS/feeder system or bus system. This estimated proportion by Logit model is further constrained by the following operational constraints.

(i) Maximum distance from origin or destination to the MRTS station, from where demand can be attracted

(ii) Distance traveled on MRTS corridor is greater than a certain minimum distance.

(iii) Distance traveled on the MRTS corridor should be at least some proportion of the total distance between the OD pair.

(iv) Availability of feeder route on one end or both ends.

As the mode choice model assigns the demand between MRTS/feeder system and Bus system, the value of different parameters assume considerable importance. To test the sensitivity of the model with respect to different parameters and decision thresholds, the following parameters, which are of considerable importance in mode choice, need to be studied under different scenarios.

- Policy time headway for Feeder bus routes
- Max distance from MRTS Station from where demand is attracted on to MRTS
- Minimum ratio of MRTS travel distance to total travel distance between Origin and Destination.
- Availability of Feeder service at one end or both ends
- Type of fare structure – slab system or unit rate

Table 7.3 gives the values of different parameters adopted for sensitivity analysis. In this table, each of the parameters at serial 3, 5 and 7 have three values; those at serial 8 and 9 have two values, while others have only one value. A full factorial design for these values will result into 108 combinations. Mode choice analysis is carried out for these 108 cases to study the behaviour of the model under different scenarios.

The fare structure considered for the sensitivity analysis are slab system and unit rate per Km and the values adopted for this exercise are given in table 7.4.

Table 7.3: Value of Parameters of Mode Choice Analysis

S.NO.	PARAMETERS	VALUES
1	Transfer Time from Feeder to MRTS (in Seconds)	300
2	Transfer Time from MRTS to Feeder (in Seconds)	300
3	Time Headway for Feeder Bus Routes (in Seconds)	300,600,900
4	Time Headway for MRTS Routes (in Seconds)	300
5	Max distance (in Km) from MRTS Station from where demand is attracted on to MRTS	8,10,12
6	Minimum distance Traveled on MRTS (Meters)	2000
7	Ratio of MRTS travel distance to total travel distance between Origin and Destination	0.2,0.3,0.4
8	Availability of Feeder bus service	One end, Both ends
9	Fare structure	Slab rate, Unit rate

Table 7.4: Fare Structure Values

S.No	Distance range (KM)	Fare structure for MRTS (Rupees)	Fare structure for Bus system/feeder buses (Rupees)
1	0-5	4	2
2	6-10	8	4
3	11-15	12	6
4	16-20	16	8
5	>21	20	10
Unit Fare (Rs/Km)		1.14	0.87

Application of the mode choice model for a scenario estimates the expected MRTS ridership for each O-D pair and the total MRTS demand matrix (1542x1542) is generated. These matrices are generated for all the 108 cases of experimental design. Total daily demand on MRTS for all the cases is presented in two Tables 7.5 and 7.6. Table 7.5 presents the results based on Slab fare structure while Table 7.6 gives the results of unit

rate structure. The estimated MRTS demand is out of the total daily demand of 7.67 million passengers on the existing bus transit network. Study of these results indicate that

- MRTS rider-ship decreases as the time headway for the feeder system increases from 300 to 900 seconds. This is because higher time headway increases the travel time making MRTS less attractive.
- MRTS rider-ship increases as the influence area for MRTS increases from 8 to 12 Km. If feeder service is provided for longer distance, it will have more attraction to MRTS.
- As the minimum travel distance over MRTS, expressed as ratio of the total trip length, increases from 0.2 to 0.4, the MRTS rider- ship decreases.
- When the feeder service is available only at one end of the trip, MRTS rider-ship will be less as compared to when service is availed at both ends.

The above trends are similar for both types of fare structure. In case of slab fare structure, the highest daily MRTS rider-ship of 1.82 million is estimated when

- Feeder routes have time headway of 300 seconds
- Maximum distance from MRTS station to stops within which demand can be attracted is 12 km
- MRTS travel distance is at least 0.2 times the total trip length between OD pairs
- Feeder routes are available at both ends

With increase of time headway for feeder routes from 300 to 900 seconds, decreasing maximum distance of MRTS station to stops from 12 Km to 8 Km and increasing ratio of MRTS travel distance to total travel distance between OD pairs from 0.2 to 0.4, the daily MRTS rider-ship will decrease from 1.82 to 1.24 million, a drop of 31.87 percent. For the cases, when the feeder service is available only at one end, the rider-ship is estimated to range between 1.65 and 1.16 million.

Table 7.6 presents the MRTS rider-ships obtained for different scenarios when unit fare rate structure is adopted. In these cases, the highest rider-ship value is 1.84 million compared to 1.82 million in case of slab fare system. The lowest estimated rider-ship is 1.26 million for unit rate fare system compared to 1.24 million in case of slab fare

system. When feeder service is made available only at one end, the estimated rider-ships for unit rate fare system range between 1.67 and 1.18 million.

Estimated MRTS demands for different scenarios indicate that the formulated mode choice appears to give realistic results. As the MRTS system is not yet operational, the validation of the model results cannot be attempted. Once the actual data of rider-ship is available, the adopted coefficients for different parameters may be adjusted.

The estimated MRTS demand matrix obtained from the mode choice model is to be used for planning of the feeder bus network. In this study, further planning is attempted based on the generated demand matrix for the following scenario:

- Slab fare system as it is easy to implement
- Feeder routes may be used at both ends
- Feeder routes have time headway of 300 seconds
- Maximum distance from MRTS station to stops within which demand can be attracted is 10 km,
- MRTS travel distance is at least 0.2 times the total trip length between OD pairs

7.4 ESTIMATION OF DEMAND FROM STOPS TO MRTS

The bus transit network of New Delhi is represented through 1542 stops, producing a total daily demand of 7.67 million. Trips produced on these stops have lot of variation, the highest trips produced are 0.19 million at the Minto road terminal stop. Out of 1542 stops of the network, a sample of 100 stops producing the highest trips in the descending order, are presented in Table 7.7. The demand expected to come to MRTS from these stops is also presented in this table. Total daily production of these 100 stops is 3.49 million, which is 45.5 percent of the total production of 1542 stops. The demand expected to come to MRTS from the 100 stops is estimated to be 0.97 million, which is 27.5 percent of trips produced. As the MRTS corridors proposed in the first phase will not cater to large area of the city, therefore the proportion of demand expected to come on MRTS is small. As more MRTS corridors are implemented, the demand for MRTS will also increase gradually.

Table 7.5: Impact of Parameters on MRTS Rider-ship (Slab Fare Structure)

S.No.	Parameters			MRTS Rider-ship (in million)	
	Time Headway for feeder bus routes (Sec)	Maximum Distance from MRTS station to a point from where demand is attracted (Km)	Ratio of MRTS travel distance to total travel distance between origin and destination	Availability of feeder routes on both ends	Availability of feeder routes on one end
1	300	8	0.2 0.3 0.4	1.61 1.50 1.33	1.48 1.40 1.25
2	300	10	0.2 0.3 0.4	1.72 1.58 1.40	1.57 1.46 1.29
3	300	12	0.2 0.3 0.4	1.82 1.66 1.46	1.65 1.52 1.34
4	600	8	0.2 0.3 0.4	1.55 1.44 1.29	1.43 1.34 1.21
5	600	10	0.2 0.3 0.4	1.65 1.52 1.35	1.51 1.41 1.25
6	600	12	0.2 0.3 0.4	1.75 1.60 1.41	1.59 1.47 1.30
7	900	8	0.2 0.3 0.4	1.48 1.39 1.24	1.37 1.29 1.16
8	900	10	0.2 0.3 0.4	1.58 1.46 1.30	1.45 1.35 1.21
9	900	12	0.2 0.3 0.4	1.67 1.53 1.35	1.52 1.41 1.25

Table 7.6: Impact of Parameters on MRTS Rider-ship (Unit Rate Fare Structure)

S.No.	Parameters			MRTS Rider-ship (in million)	
	Time Headway for feeder bus routes (Sec)	Maximum Distance from MRTS station to a point from where demand is attracted (Km)	Ratio of MRTS travel distance to total travel distance between origin and destination	Availability of feeder routes on both ends	Availability of feeder routes on one end
1	300	8	0.2 0.3 0.4	1.64 1.53 1.36	1.51 1.43 1.28
2	300	10	0.2 0.3 0.4	1.74 1.60 1.42	1.59 1.48 1.31
3	300	12	0.2 0.3 0.4	1.84 1.68 1.48	1.67 1.54 1.36
4	600	8	0.2 0.3 0.4	1.57 1.46 1.31	1.45 1.36 1.23
5	600	10	0.2 0.3 0.4	1.67 1.54 1.37	1.53 1.43 1.27
6	600	12	0.2 0.3 0.4	1.77 1.63 1.43	1.61 1.49 1.32
7	900	8	0.2 0.3 0.4	1.51 1.41 1.26	1.39 1.32 1.18
8	900	10	0.2 0.3 0.4	1.61 1.48 1.32	1.47 1.38 1.23
9	900	12	0.2 0.3 0.4	1.70 1.56 1.37	1.54 1.44 1.27

The total demand coming to the MRTS stations is calculated and is presented in the table 7.8. It is observed that highest demand of 0.17 million is expected on the New Delhi MRTS station. As the proposed two stations at Pehladpur and Daultpur are not yet connected with the road network, therefore the estimated demand on these stations is not worked out. Five MRTS stations have a daily station load of greater than 0.1 million passengers, eight stations have demand between 50,000 to 0.1 million, and only three stations have demand of less than 10,000 passengers. The total demand attracted from 1542 stops to the MRTS is 1.72 million, which is 22.4 percent of total demand. The estimated station loads as illustrated in Table 7.8 are also helpful for scheduling of train trips on the MRTS system.

7.5 INFLUENCE AREA OF MRTS STATIONS

To facilitate the generation of feeder routes for trips makers, a geographical area termed as influence area, is to be delineated for each MRTS station. The three models evolved in the study methodology of feeder bus planning system for demarcating the influence area of each MRTS station are heuristic, fuzzy and neural network. Broadly, these models can be categorized into two approaches.

(i) Heuristic approach

(ii) Clustering approach.

In the heuristic approach, Influence area is decided after estimating the demand potential of stops to MRTS subject to the constraints of maximum distance and the ratio of travel on MRTS to total travel between OD pairs. The analysis is done at the micro level and only those stops, which contribute some demand to MRTS, are considered. In the process, some stops may lie in the influence area of more than one MRTS station. Stops lying in the influence area but not contributing any demand to MRTS are not considered for further analysis. This approach allows user interaction with the machine and facilitates the demarcation of influence area of MRTS stations individually.

Table 7.7: Demand Attracted from Top 100 Stops to MRTS

S.No.	Stop Code	Production	Attraction to MRTS	S.No.	Stop Code	Production	Attraction to MRTS
1	667	185997	73977	51	1412	28018	7876
2	460	121693	35886	52	1371	27516	7050
3	1508	81360	0	53	1515	27157	0
4	1370	76977	46906	54	1066	26989	8496
5	1398	74017	20986	55	1446	26910	1412
6	1363	71297	19659	56	1485	26582	11715
7	1383	69469	22814	57	1496	26456	8351
8	1366	69309	41923	58	852	26413	2169
9	315	65460	20805	59	1484	26050	8579
10	1411	57515	13174	60	1359	25990	2863
11	185	56268	31359	61	1418	25870	6901
12	1054	55122	5545	62	1430	25684	5053
13	1388	54960	7861	63	6	25517	7788
14	1533	54352	8091	64	58	25420	10571
15	279	53205	30389	65	1443	24939	2847
16	1074	50748	20789	66	1494	24663	5551
17	1460	49237	8019	67	61	24231	11351
18	953	45799	4676	68	1382	24228	4624
19	1413	44700	18538	69	1499	24178	5005
20	1350	44371	11935	70	1358	23999	2729
21	1392	41732	12624	71	1395	23665	3172
22	1489	41004	19814	72	1476	23390	3115
23	1453	40355	19932	73	1391	23126	6003
24	1442	39113	4735	74	1445	22660	1279
25	1408	39008	4685	75	1506	22592	6631
26	863	38494	0	76	1495	22473	3129
27	50	35641	15430	77	1438	22466	7071
28	1475	35551	5888	78	3	21600	6925
29	1348	35307	6569	79	1441	21240	2501
30	1491	35241	5660	80	752	20906	0
31	728	34845	11143	81	1502	20180	3974
32	698	34227	3801	82	1433	20093	0
33	1471	33395	12928	83	218	20079	10087
34	284	32806	13274	84	300	19858	6164
35	1365	32389	10871	85	1477	19844	5538
36	1470	32343	5389	86	898	19836	2715
37	405	31711	8364	87	1501	19765	5974
38	1357	31375	4359	88	451	19640	5089
39	1503	31126	1858	89	1452	19249	5284
40	456	30389	13322	90	1404	19038	3027
41	1107	30365	4012	91	1493	18807	4251
42	230	30075	20042	92	319	18547	4042
43	1468	29667	12347	93	715	17935	0
44	1449	29370	9429	94	1463	17899	0
45	1035	29270	4224	95	1384	17410	8455
46	1467	29193	12456	96	63	17288	6800
47	1390	28889	8503	97	1510	17062	0
48	1096	28858	5920	98	1483	16967	3466
49	966	28646	0	99	54	16910	8909
50	1500	28626	6695	100	450	16762	7508

Productions of top 100 stops : - **3494964** *Demand Attracted to MRTS*: - **959646**

*Total Productions of 1542 stops:- **7669330***

Table 7.8: Estimated Load on MRTS Stations

MRTS Station Code	MRTS Station Name	MRTS Station load
5001	BARWALA	29033
5004	RITHALA	9454
5005	ROHINI WEST	24553
5006	ROHINI EAST	18206
5007	PITAMPURA	96096
5008	KOHAT ENCLAVE	43601
5009	WAZIRPUR	89837
5010	LAWRENCE ROAD	10530
5011	KANAHYA NAGAR	68073
5012	TRI NAGAR	118051
5013	VIVEKANANDA PURI	87740
5014	PRATAP NAGAR	1290
5015	PUL BANGASH	133928
5016	TIS HAZARI	54995
5017	ISBT	60187
5018	SHASTRI PARK	96602
5019	GAUTAM PURI	40164
5020	SEELAMPUR	44123
5021	SHAHDRA	130681
5022	VISHVA VIDYALAYA	84925
5023	OLD SECRETARIAT	12881
5024	CIVIL LINES	18904
5025	DELHI MAIN	7045
5026	CHAWRI BAZAR	46534
5027	NEW DELHI	174807
5028	CONNAUGHT PLACE	40874
5029	PATEL CHOWK	44312
5030	CENTRAL SECRETARIAT	129447
Total MRTS stations load		**1716873**

In the clustering approach using Fuzzy-c-means and Self-organizing map, all the 1542 stops of the network are partitioned into a defined number of clusters. These clusters contain the nodes and the boundary joining these nodes will deliver certain geographical area. This area along with the enclosed nodes is assigned to one or the other MRTS station irrespective of the distance constraint. The influence area with this approach is firstly demarcated without taking any distance constraint. All the stops of the study area are considered and are assigned to the MRTS stations. Since all the MRTS stations are assigned the influence area in one go after the clusters are obtained, therefore this approach is best suited for the initial planning. But this approach assigns one node to only one MRTS station, though there may be considerable demand from a stop to the other MRTS stations.

Table 7.9 depicts the number of stops contributing in the influence area of MRTS station using the models illustrated in methodology. Heuristic model allows only those stops to come in the influence area of MRTS stations, which contribute demand to the MRTS. Therefore, 1078 stops from a total of 1542 stops of the network are assigned to the influence area of MRTS stations. Some stops are overlapping in the influence area of more than one MRTS station. Pehladpur and Daultpur stations do not have any stops in the influence area by heuristic approach because in the available information of network, these stations are not linked to the road network.

For Self-organizing map and Fuzzy-c-means clustering approach, the figures shown in the table are taken up for a particular illustration of 100 clusters. All the 1542 stops are assigned to the MRTS stations though there may not be any demand from some of the stops to the MRTS. It is observed from the table that the number of stops lying in Influence area of MRTS stations is reasonably very high. Distance constraints are therefore need to be imposed on the influence area of MRTS stations. Table 7.10 presents the comparison of number of stops in the influence area of MRTS stations, if distance constraints of 10 Km, 12 Km and 15 Km are affected on clusters obtained through Self organizing map and Fuzzy-c-means clustering approach. With a distance constraint of 10 Km, the number of stops within the influence area of MRTS stations seems to be

compatible for Heuristic and self-organizing map (SOM) approaches. But the results of Fuzzy-c-means clustering are significantly different.

As the heuristic approach works out the influence area for each MRTS station on a micro-analysis basis of each OD pair, it appears to be more rational to use this approach for further analysis of feeder route generation.

Table 7.9: Number of Stops in Influence Area of MRTS Stations with the three Approaches

MRTS Station Code	MRTS Station Name	Number of stops in I.A of MRTS stations		
		Mode choice analysis (Heuristic approach)	Number of clusters =100	
			Self-organizing map	Fuzzy- C-means clustering
5001	BARWALA	27	199	101
5002	PEHLADPUR	-	9	17
5003	DAULTPUR	-	-	-
5004	RITHALA	19	64	10
5005	ROHINI WEST	20	39	16
5006	ROHINI EAST	29	-	16
5007	PITAMPURA	56	37	23
5008	KOHAT ENCLAVE	37	56	15
5009	WAZIRPUR	44	19	22
5010	LAWRENCE ROAD	11	26	25
5011	KANAHYA NAGAR	27	23	80
5012	TRI NAGAR	85	120	60
5013	VIVEKANANDA PURI	43	20	-
5014	PRATAP NAGAR	4	-	34
5015	PUL BANGASH	42	48	14
5016	TIS HAZARI	12	17	-
5017	ISBT	14	-	-
5018	SHASTRI PARK	64	8	16
5019	GAUTAM PURI	17	11	26
5020	SEELAMPUR	58	95	12
5021	SHAHDRA	56	144	92
5022	VISHVA VIDYALAYA	50	58	53
5023	OLD SECRETARIAT	19	12	26
5024	CIVIL LINES	20	-	14
5025	DELHI MAIN	2	-	12
5026	CHAWRI BAZAR	3	-	-
5027	NEW DELHI	58	17	37
5028	CONNAUGHT PLACE	40	44	82
5029	PATEL CHOWK	69	41	110
5030	CENTRAL SECRETARIAT	152	435	629

Table 7.10: Comparison of three Approaches for Number of Stops within I.A of MRTS Stations (Distance constraint – 10Km, 12 Km and 15 Km)

MRTS Station Code	Number of stops in I.A of MRTS stations						
	Mode choice analysis (Heuristic approach)	Number of clusters =100					
		Distance Constraint = 10 Km		Distance Constraint = 12 Km		Distance Constraint = 15 Km	
		SOM	FCM	SOM	FCM	SOM	FCM
5001	27	38	-	58	-	81	-
5002	-	-	-	-	-	-	-
5003	-	-	-	-	-	-	-
5004	19	22	-	24	-	29	-
5005	20	39	-	39	-	39	7
5006	29	-	-	-	-	-	5
5007	56	19	2	21	4	34	6
5008	37	39	-	55	-	56	11
5009	44	19	-	19	-	19	-
5010	11	26	-	26	-	26	-
5011	27	23	7	23	13	23	48
5012	85	84	27	102	42	118	58
5013	43	20	-	20	-	20	-
5014	4	-	4	-	13	-	27
5015	42	48	1	48	10	48	14
5016	12	17	-	17	-	17	-
5017	14	-	-	-	-	-	-
5018	64	8	-	8	1	8	15
5019	17	11	-	11	-	11	-
5020	58	93	12	95	26	95	26
5021	56	103	31	115	43	137	66
5022	50	56	-	58	-	58	-
5023	19	12	-	12	-	12	-
5024	20	-	-	-	2	-	14
5025	2	-	10	-	12	-	12
5026	3	-	-	-	-	-	-
5027	58	17	37	17	37	17	37
5028	40	44	47	45	73	45	82
5029	69	39	70	39	85	41	90
5030	152	219	199	288	285	354	396

7.6 GENERATION OF FEEDER ROUTES

Optimal feeder routes for the influence area of each MRTS station are generated as per the methodology discussed earlier. The process starts by identifying the farthest unconnected stop from the MRTS as a terminal. This choice is also subject to constraints

of demand and distance from MRTS station. Alternative paths are generated between the MRTS station and the identified terminal. The first path generated is the shortest between the two terminals. The shortest path is deviated to a certain context by introducing a meandering factor, so that more nodes which are untouched and in close vicinity of the shortest path, can be accommodated in the alternative paths. The number of alternative paths depends upon the meandering factor. Alternative paths are evaluated on the basis of 'Desire-passenger-km per km' criterion. The path, which has the maximum desire-passenger-km per km value, is selected as the optimal between the MRTS station and bus terminal. The process continues till no further terminal could be identified in the influence area.

For illustration purpose, a terminal stop Bair Sarai selected within the influence area of Central Secretariat MRTS station is taken up as an example. Alternative paths are generated between the terminal stop and Central Secretariat MRTS station. Twenty-eight alternative paths have been generated with a meandering factor of 1.25. The alternative paths generated between the Bair Sarai terminal and Central Secretariat MRTS station are presented in Table 7.11. Table 7.12 presents the statistics of alternative paths generated between MRTS station and the selected terminal. Based on the criteria of Maximum 'Desire passenger-km per km', the alternative sixteen with a maximum value of 6804 is selected as the optimal path.

Feeder routes are generated for the influence area of all MRTS stations. Table 7.13 presents the statistics of optimal routes generated for the Barwala MRTS station. It is observed that the lengths of the optimal feeder routes varies from 4.3 Km to 11.2 Km, the demand satisfied along the feeder routes varies from 1040 to 8963, and the utilization factor for optimally feeder routes lies between 0.79 and 1.00. The highest value (8881) of desired passenger-km per km is for Route No. 9, while the lowest value of 701 is observed for Route No.1. The paths of the optimally generated feeder routes for Barwala station are shown in figures 7.3 to 7.11.

Table 7.11: Alternatives Paths Generated between Bair Sarai (Terminal) and Central Secretariat (MRTS Station)

Alt. No.	Origin stop	MRTS station	Intermediate stops
1	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
2	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 938 3247 692 3246 3245 3237 3239 3531 3238 1438 3173
3	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 919 3228 3227 918 917 3234 3235 3532 1376 3172 914 3136 1393 726 3155 727 1473 3137 1406 3173
4	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 741 3236 3533 738 3237 737 1430 925 3530 736 3138
5	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
6	821	5030	3589 841 3386 3426 1458 3376 846 819 845 1032 847 3367 3368 1033 3370 3371 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
7	821	5030	829 831 830 832 3428 833 967 837 836 3433 1407 838 3441 1049 880 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
8	821	5030	3589 839 3432 3433 1407 838 3441 1049 880 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
9	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 883 881 882 3353 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
10	821	5030	3589 841 3386 1041 3375 1042 3380 884 3352 1049 880 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
11	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 919 3228 911 910 3226 3227 918 917 3234 3235 3532 1376 3173
12	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 919 3228 911 910 3226 912 1047 913 3136 3137 1406 3173
13	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 919 3228 3227 918 917 3234 3235 916 3240 3239 3531 3238 1438 3173
14	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 3244 3245 3250 926 3145 927 925 3530 736 3138
15	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3232 937 3233 3241 3239 3531 3238 1438 3173

16	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 1533 3389 3269 947 943 946 3247 3244 939 3236 3533 740 3241 3239 3531 3238 1438 3173
17	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3592 950 3359 3357 3590 1051 1050 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
18	821	5030	3589 839 3432 3433 3434 964 961 960 3442 3441 1049 880 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
19	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 3373 1044 1043 1035 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
20	821	5030	3589 841 3386 1041 3375 1042 3380 3382 3381 1039 3373 1044 1043 1035 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
21	821	5030	3589 841 3386 3426 1458 3376 1040 827 3374 1495 3381 1039 3373 1044 1043 1035 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
22	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1053 3592 950 3359 3357 3590 1051 1050 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
23	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 1055 3362 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
24	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 3244 3245 3250 926 3145 3139 3530 736 3138
25	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3230 920 935 3225 908 911 3228 3227 918 917 3234 3235 3532 1376 3173
26	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 3244 3245 940 929 3251 3250 926 3145 927 925 3530 736 3138
27	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 3244 3245 940 929 3251 3252 926 3145 927 925 3530 736 3138
28	821	5030	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 3669 3389 1533 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173

Table 7.12: Statistics for Alternative Paths Generated for a Route

Alternative Number	Route Length	Satisfied demand	Demand satisfied per km	Utilization Coefficient	Passenger-Km	Passenger-Km per Km
1	9713	11293	1163	1.00	65828	6777
2	11548	10252	888	0.83	64876	5618
3	12098	11892	983	0.67	66537	5500
4	10160	15219	1498	0.956	68681	6760
5	9895	10070	1018	0.972	63718	6439
6	11433	4599	402	0.976	24248	2121
7	11897	4301	362	0.984	25965	2182
8	10711	3982	372	0.991	23000	2147
9	10772	6992	649	0.982	42416	3938
10	10798	4646	430	0.976	29061	2691
11	11264	11615	1031	0.816	66910	5940
12	11498	10648	926	0.775	65890	5731
13	10142	11110	1095	0.932	66111	6519
14	10934	10032	918	0.84	63343	5793
15	9838	10505	1068	0.982	64662	6573
16	12072	14653	1214	0.81	82135	6804
17	10639	11033	1037	0.906	69116	6496
18	11878	3611	304	0.981	20374	1715
19	10612	8775	827	0.965	53198	5013
20	10632	7222	679	0.986	42580	4005
21	11051	8828	799	0.99	55466	5019
22	10728	7290	680	0.935	46983	4379
23	9821	10745	1094	0.987	64182	6535
24	11388	9776	858	0.788	63103	5541
25	11771	11702	994	0.785	67941	5772
26	11908	10606	891	0.749	64640	5428
27	11914	10606	890	0.748	64640	5426
28	11899	14126	1187	0.855	80335	6751

Table 7.13: Statistics of Feeder Routes Generated for Barwala MRTS Station

MRTS Stn.	Route No.	Route Length	Satisfied demand	Demand Per_km	Utiliz. Factor	Pass_Km	Pass_km Per Km
5001	1	11170	2259	202	0.775	7834	701
5001	2	9814	3850	392	1.000	- 29641	3020
5001	3	9767	1343	138	1.000	9917	1015
5001	4	10542	4249	403	0.987	28429	2697
5001	5	10887	3195	293	0.800	15366	1411
5001	6	11468	2902	253	0.789	12524	1092
5001	7	9302	1228	132	0.992	8633	928
5001	8	7080	1040	147	1.000	5276	745
5001	9	4324	8963	2073	1.000	38401	8881

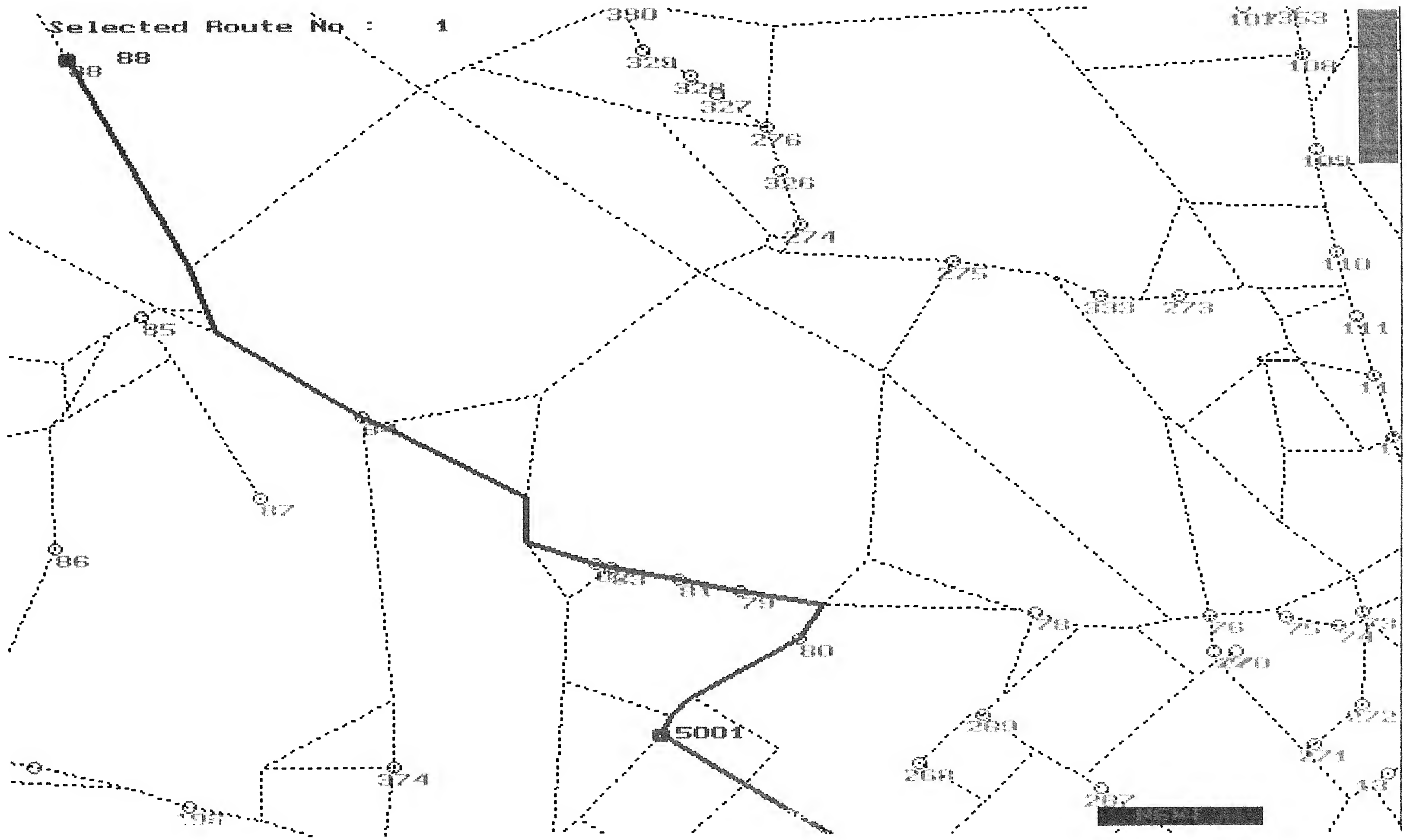


Figure 7.3: Optimally Generated Feeder Route No. 1 for Barwala Station

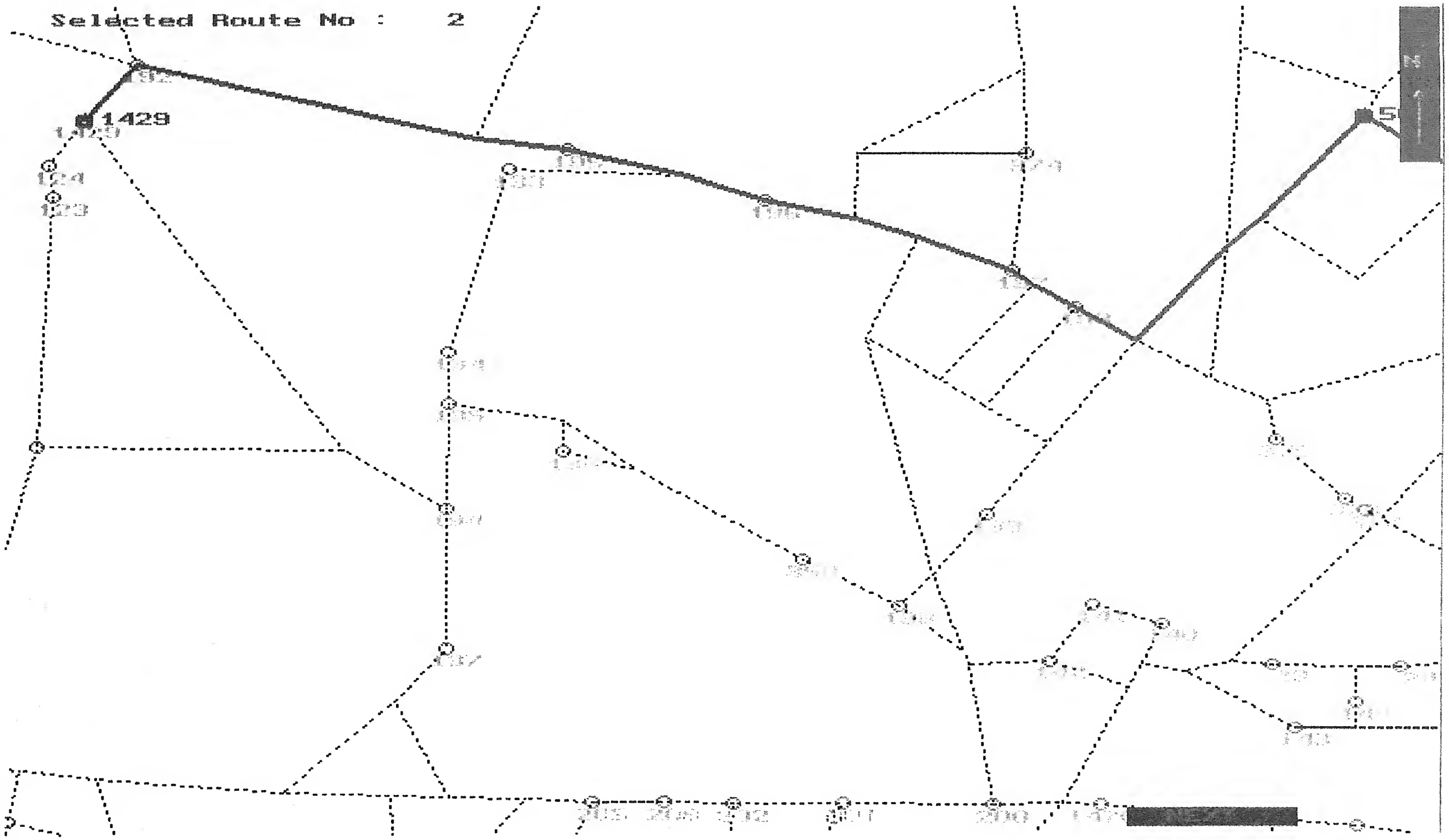


Figure 7.4: Optimally Generated Feeder Route No. 2 for Barwala Station

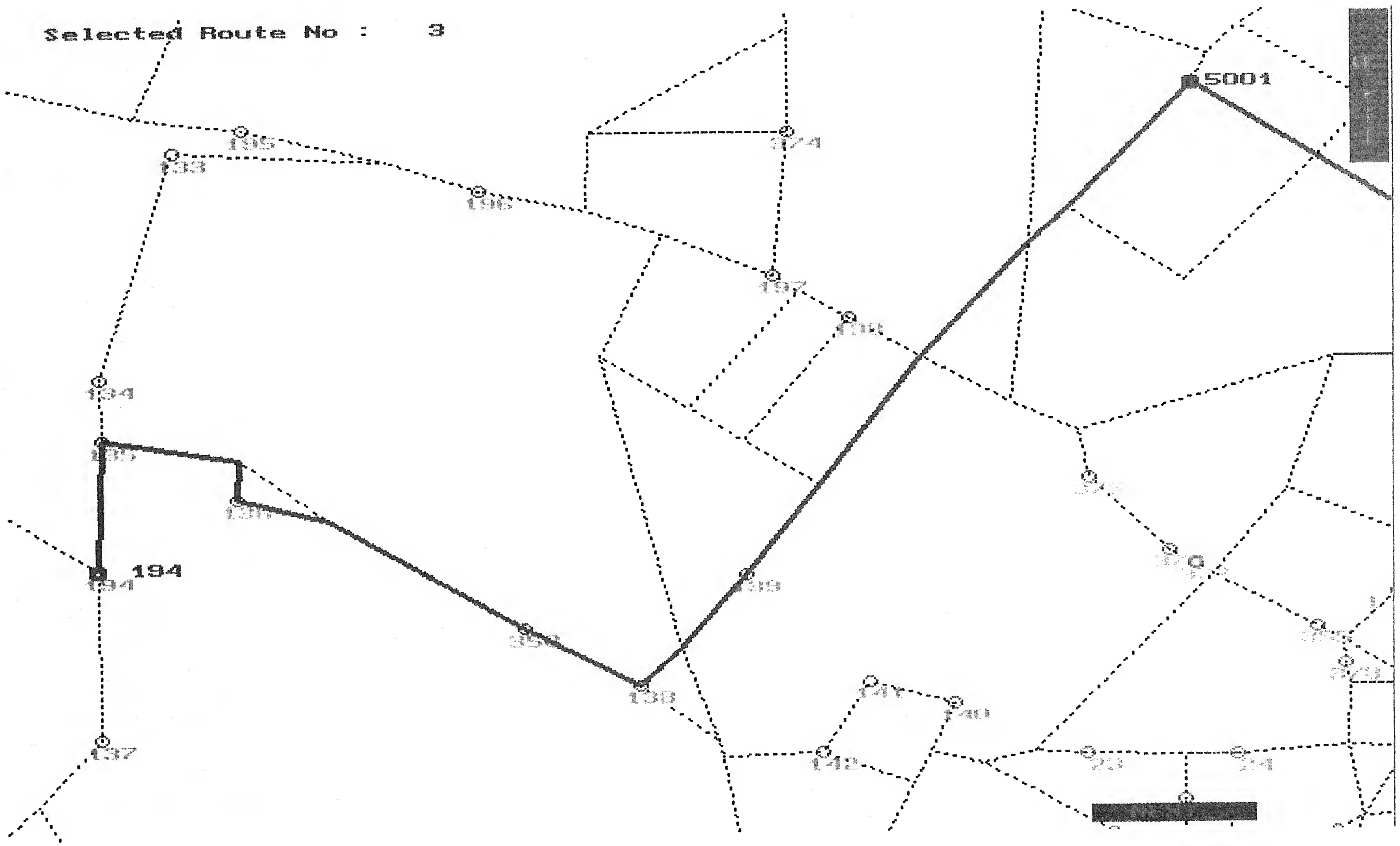


Figure 7.5: Optimally Generated Feeder Route No. 3 for Barwala Station

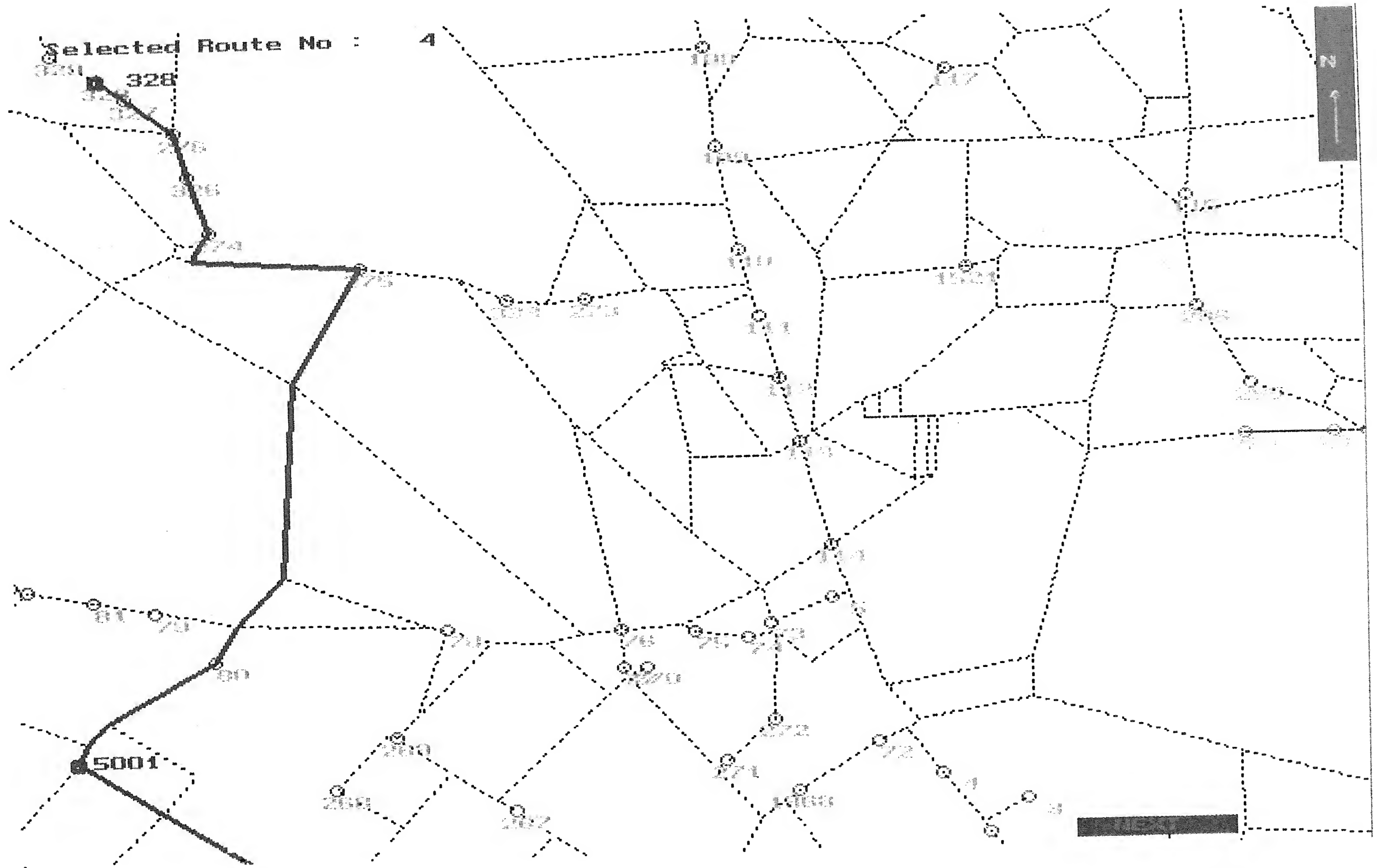


Figure 7.6: Optimally Generated Feeder Route No. 4 for Barwala Station

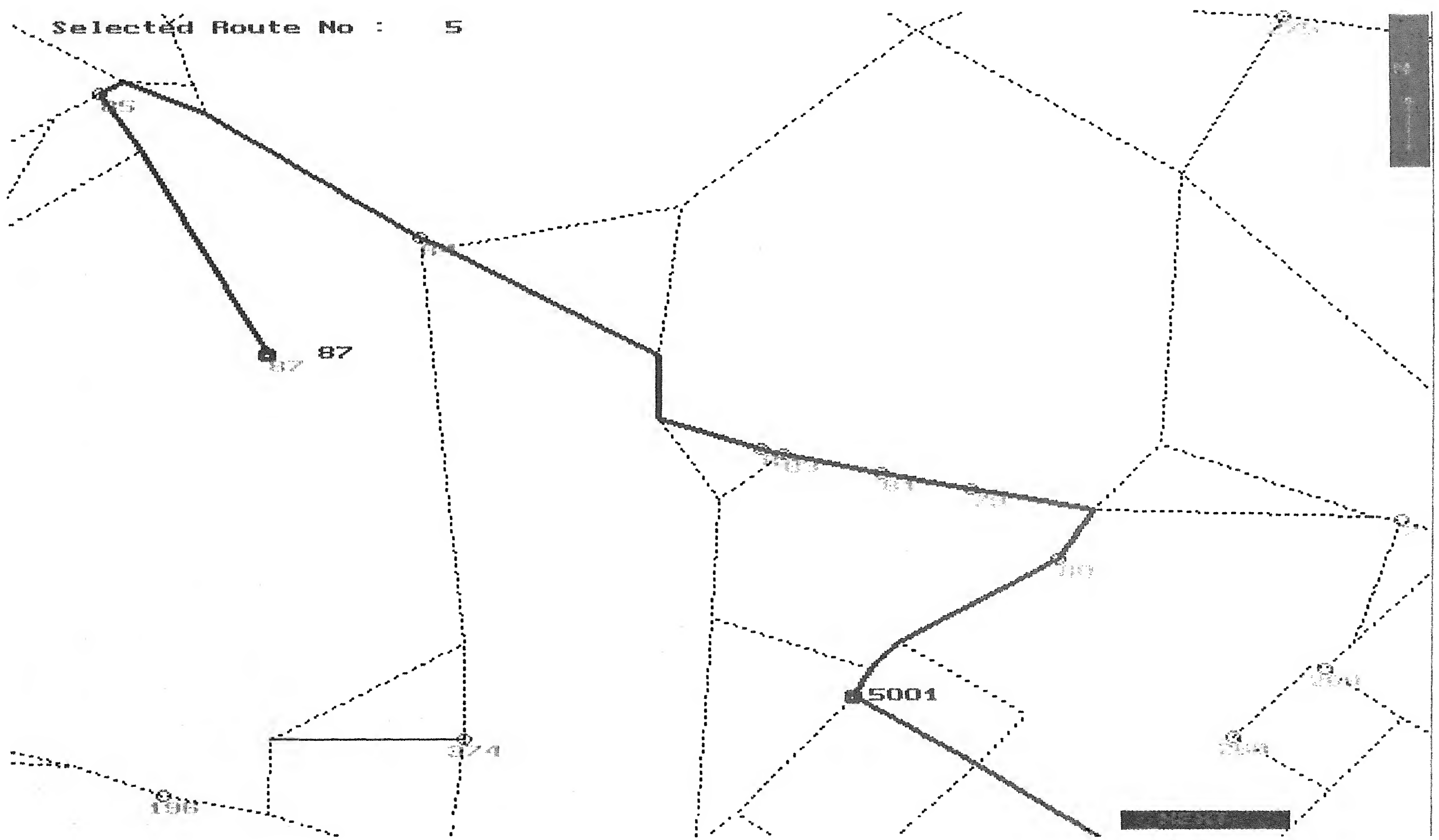


Figure 7.7: Optimally Generated Feeder Route No. 5 for Barwala Station

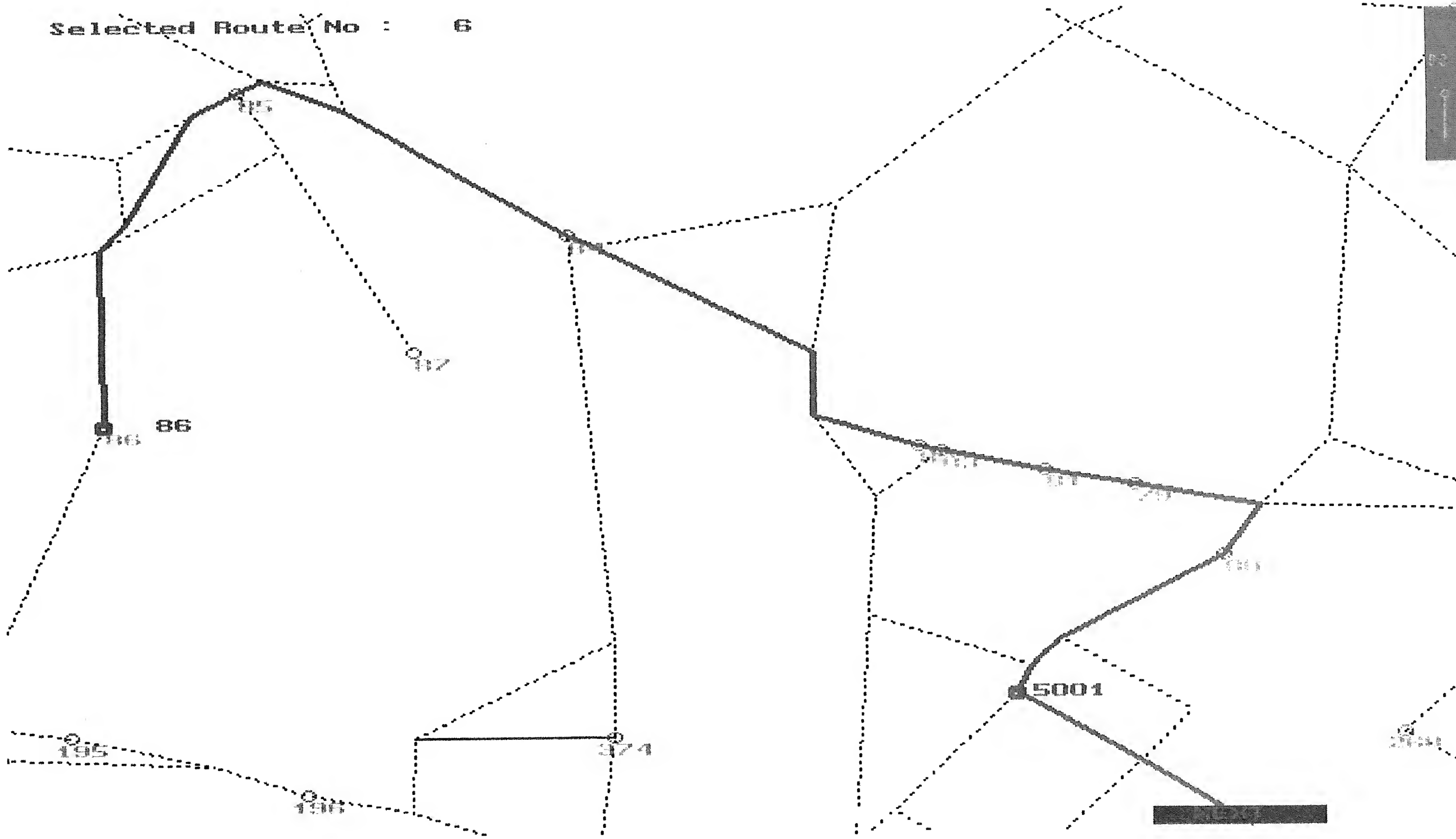


Figure 7.8: Optimally Generated Feeder Route No. 6 for Barwala Station

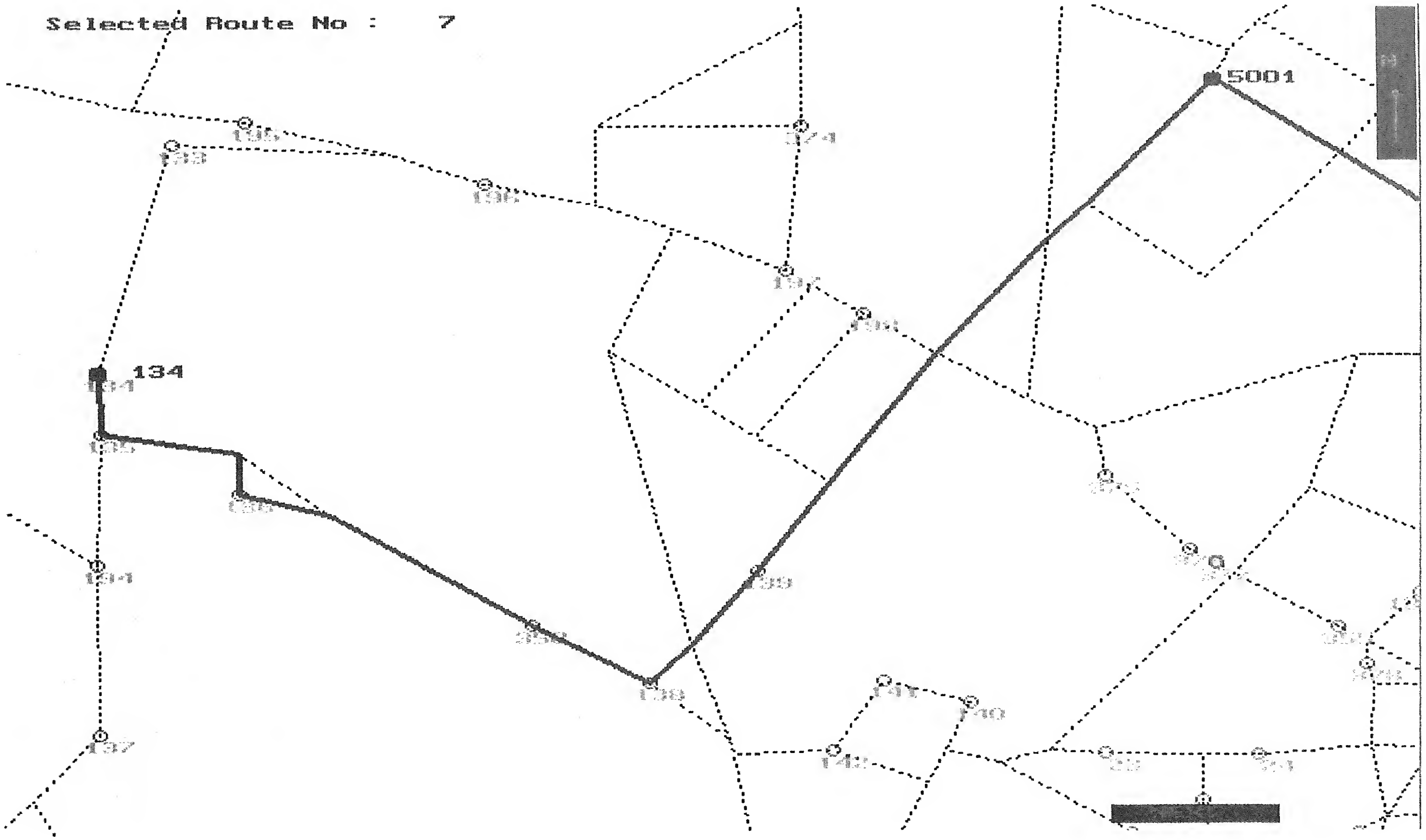


Figure 7.9: Optimally Generated Feeder Route No. 7 for Barwala Station

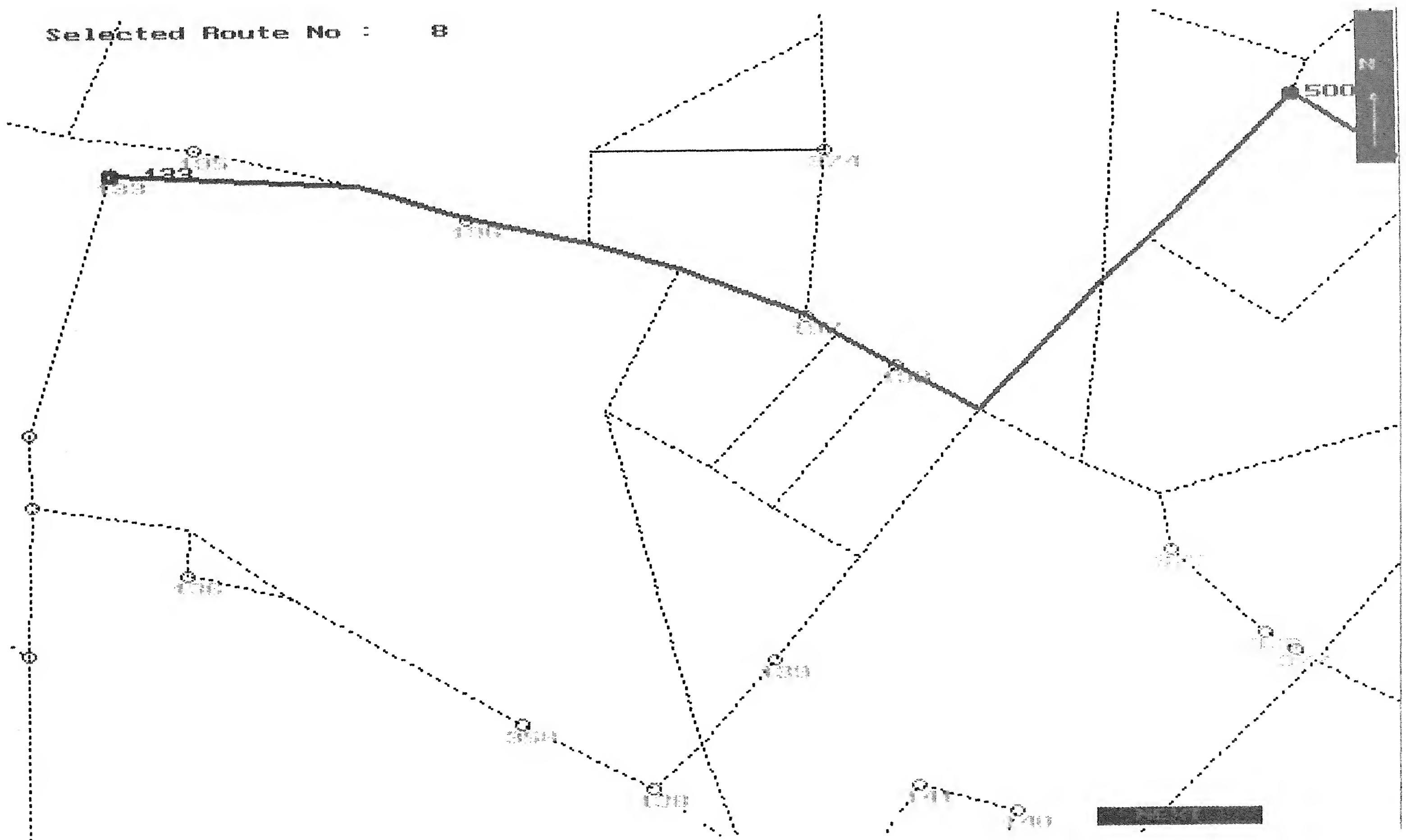


Figure 7.10: Optimally Generated Feeder Route No. 8 for Barwala Station

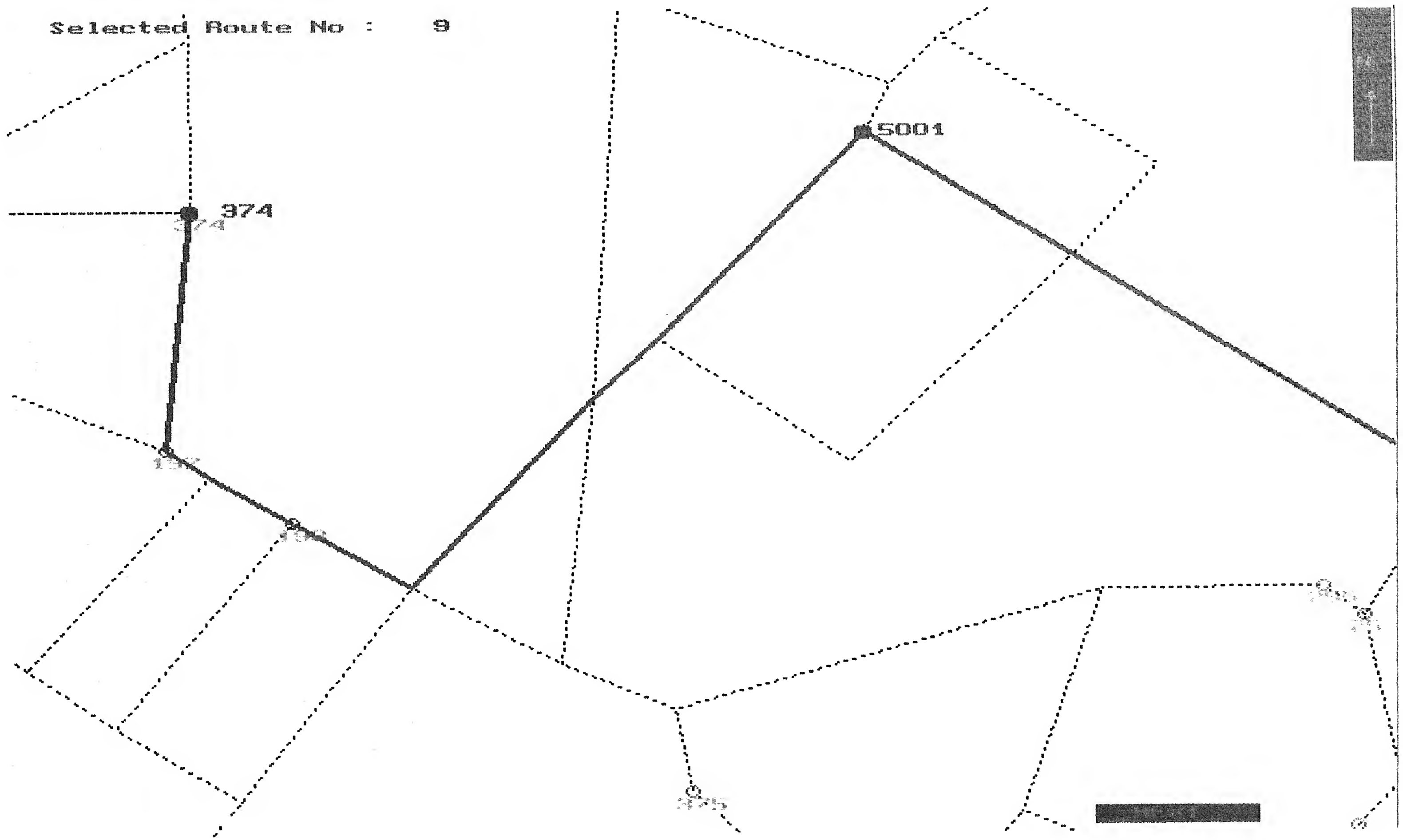


Figure 7.11: Optimally Generated Feeder Route No. 9 for Barwala Station

The various alternative paths generated between the MRTS station and the selected terminal depends upon the meandering factor. If the meandering factor adopted is small, then fewer alternatives will be generated and fewer stops lying in the vicinity of shortest path will be included in the alternatives. In the process some stops may remain untouched within the influence area of a MRTS station and demand may not be optimally served. For large meandering factor, the area served in the vicinity of the shortest path will be more because more stops will be included in the alternative paths. Alternative paths generated with large meandering factor will be more and routes generated will be of longer length. The trip makers may therefore be forced to travel longer distances. Smaller meandering factor is beneficial to the trip maker whereas longer meandering factor is useful to the operator point of view. In this paradoxical condition, it is necessary to choose optimal meandering factor for generating the alternative paths so as to satisfy both trip makers and operators.

Computational experiments have been conducted on meandering factor for generating the feeder routes of all the MRTS stations. The values adopted for experimentation on meandering factor are 1.15, 1.25 and 1.35. Feeder routes are generated in the influence area of each MRTS station subject to a minimum distance constraint of 4 km. Table 7.14 presents the number of feeder routes generated and the average route length for all the MRTS stations. It is observed that as the meandering factor increases from 1.15 to 1.35, the total number of feeder routes generated for all MRTS stations decreases. For all MRTS stations, 184 feeder routes generated with a meandering factor of 1.15 decreases to 173, if meander factor is increased to 1.25 and further slightly reduced to 170 with a meandering factor of 1.35. The maximum average route length observed for station 5001 is 9.4 Km with meandering factor of 1.15, which increased to 11 km with increase in meandering factor to 1.35.

As the variation in meandering factor in generating feeder routes for all MRTS stations has not much pronounced effect on the characteristics of feeder routes, therefore a meandering factor of 1.25 is assumed to be more rational for further analysis.

Table 7.14: Characteristics of Feeder Routes for all MRTS Stations (Meandering factor = 1.15, 1.25 and 1.35)

MRTS Station	Meander Factor=1.15		Meander Factor=1.25		Meander Factor=1.35	
	Av. Route Length	Number of feeder routes	Av. Route Length	Number of feeder routes	Av. Route Length	Number of feeder routes
5001	9.4	9	9.6	9	11.0	7
5002	-	-	-	-	-	-
5003	-	-	-	-	-	-
5004	5.7	4	6.3	4	6.5	4
5005	5.9	4	7.6	4	8.0	4
5006	7.7	6	7.9	6	7.8	7
5007	7.8	14	8.3	13	9.4	10
5008	8.7	4	8.7	4	7.9	5
5009	7.0	10	7.5	10	7.9	10
5010	-	-	-	-	-	-
5011	5.0	3	6.0	2	6.0	2
5012	8.4	15	8.8	15	9.0	16
5013	4.6	4	4.6	4	4.9	4
5014	-	-	-	-	-	-
5015	-	-	-	-	-	-
5016	-	-	-	-	-	-
5017	5.6	1	5.5	2	6.0	2
5018	7.0	15	7.3	14	7.8	14
5019	5.4	4	6.1	3	5.9	3
5020	7.6	10	9.0	9	9.7	8
5021	5.6	12	6.2	10	6.5	9
5022	7.8	4	7.8	4	9.8	4
5023	5.7	5	5.7	5	5.7	5
5024	4.8	1	4.8	1	4.8	1
5025	-	-	-	-	-	-
5026	-	-	-	-	-	-
5027	8.3	9	8.6	9	9.5	8
5028	6.4	5	7.2	4	8.2	4
5029	7.8	11	8.6	12	8.8	12
5030	8.4	34	9.1	29	9.8	31

The choice of road terminal for the feeder route also depends upon the minimum specified distance constraint. To test the sensitivity of distance constraint, optimal feeder routes are generated for two different minimum constraint distance of 2 and 4 Km. Table 7.15 specifies the characteristics of routes generated for both the cases.

A total of 259 routes are generated for all the MRTS stations, when the specified minimum distance is 2 km. In this case, maximum of 32 feeder routes are obtained for MRTS station 5030. The average route length for different stations ranges between 3.3 to 9.6 km, and the longest feeder route is 12.4 km long for Pitampura MRTS station.

With a minimum distance constraint of 2 km, it is observed that many routes are very short. In order to avoid too much congestion of routes near the stations, when the minimum distance constraint is increased to 4 km, the number of optimal feeder routes reduces to 173 and the average route length for different stations ranges from 4.6 to 9.6 km. Though the maximum average feeder route remains static at 9.6 Km but the minimum average route length has increased from 3.3 km to 4.6 km. The frequency distribution of 173 generated feeder routes for all MRTS stations is shown in Figure 7.12 and the path for each route is given in Appendix-D.

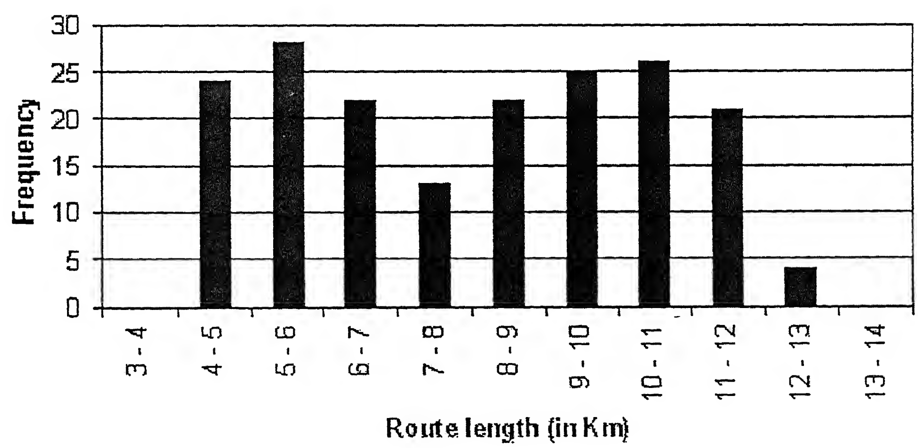


Figure 7.12: Frequency Distribution of Feeder Routes for all MRTS Stations

Table 7.15: Feeder Route Length Characteristics (Meandering factor = 1.25)

MRTS Station	Feeder Route Length Characteristics with (min. dis constraint =2 km)			No. of Feeder routes generated	Feeder Route Length Characteristics with (min. dis constraint =4 km)			No. of Feeder routes generated
	Max. length	Min. Length	Av. Length		Max. length	Min. length	Av. Length	
5001	11.4	4.5	9.6	9	11.4	4.5	9.6	9
5002	-	-	-	-	-	-	-	-
5003	-	-	-	-	-	-	-	-
5004	7.1	2.5	4.9	8	7.1	5.7	6.3	4
5005	11.1	2.8	5.7	7	11.1	4.3	7.6	4
5006	11.1	2.4	6.2	9	11.1	5.7	7.9	6
5007	12.4	2.2	6.9	17	12.4	4.4	8.3	13
5008	9.6	2.3	6.7	6	9.6	6.9	8.7	4
5009	11.3	2.9	7.1	11	11.3	4.4	7.5	10
5010	3.3	3.3	3.3	1	-	-	-	-
5011	6.2	2.8	4.0	7	6.2	5.7	6.0	2
5012	11.4	2.8	8.2	17	11.4	4.4	8.8	15
5013	4.7	2.3	3.7	11	4.7	4.5	4.6	4
5014	-	-	-	-	-	-	-	-
5015	4.7	2.2	3.3	8	-	-	-	-
5016	3.3	3.3	3.3	1	-	-	-	-
5017	6.6	3.0	4.6	3	6.6	4.3	5.5	2
5018	10.5	4.2	6.8	17	10.5	4.7	7.3	14
5019	6.6	3.0	5.0	5	6.6	5.8	6.1	3
5020	12.4	2.4	7.0	14	12.4	4.8	9.0	9
5021	10.1	3.7	5.8	13	10.1	4.9	6.2	10
5022	9.8	2.7	5.2	9	9.8	4.9	7.8	4
5023	7.0	4.3	5.7	5	7.0	4.3	5.7	5
5024	4.8	2.7	3.7	6	4.8	4.8	4.8	1
5025	-	-	-	-	-	-	-	-
5026	-	-	-	-	-	-	-	-
5027	10.1	2.7	6.4	15	11.5	4.3	8.6	9
5028	10.3	2.2	4.6	11	10.3	4.6	7.2	4
5029	11.1	2.7	7.3	17	11.1	6.5	8.6	12
5030	11.7	2.6	8.5	32	12.3	4.3	9.1	29
Feeder routes for all MRTS stations				259				173

7.7 SCHEDULING PLAN FOR FEEDER ROUTES

The objective of scheduling plan is to allocate the buses optimally to the generated feeder routes of MRTS. The heuristic algorithm developed in the study methodology schedules the bus trips for peak period and off-peak period depending upon the variation of demand during different periods of the day. Assigning weightage to different hours of operation, the equivalent peak hours of operation for public transportation is obtained. Type of bus (standard size or smaller size) to be operated on a route is selected based on the demand, policy headway and road characteristics along the path. The desired level of service for operation is defined in terms of average bus load and maximum bus load. The maximum passenger link flow and average link flow along the path are used to determine the number of bus trips to be operated on a route. The number of buses to be assigned on a route and the operating headway are determined. Various characteristics of the scheduling plan, namely system waiting time, total km operated and km operated per bus for the scheduling period are also estimated.

In the metropolitan city of New Delhi, the scheduling of buses is made for three periods of the day namely morning peak, mid day and evening peak period. It is observed that both peak periods are of three-hour duration and account for 25 percent of the daily demand. The mid day period of six hour duration accounts for 31 percent of the daily demand. Though the fleet size required will depend upon the peak period demand, the scheduling for the mid day period identifies the buses that can be withdrawn from MRTS feeder route system. Table 7.16 specifies the distribution of daily travel demand for peak and off-periods.

Table 7.16: Distribution of Daily Travel Demand

Period	Duration of day	Period Demand (Percent of daily demand)
Peak period	8 - 11 A.M.	25
	5 – 8 P.M.	25
Mid-day period	11 A.M. – 5 P.M	31

The peak hours demands more frequent service than the lean hours of the day. Accordingly the total 15 hours of operation for public transport in the metropolitan city area is converted into equivalent 11 hours of peak period by assigning weightages to different hours of operation. All the generated feeder routes are to be operated at certain minimum frequency level or maximum policy headway. Minimum policy headway is also defined based on operational constraints. The limits of headway for feeder bus routes adopted in the work are given in the Table 7.17.

Table 7.17: Limits of Time Headways

Period	Minimum headway (Minutes)	Maximum headway (Minutes)
Peak period	3	15
Mid-day period	3	20

At the maximum policy headway, the number daily bus trips for a route are (11*60) / 20 = 33. If the capacity of bus is assumed as 50, then the minimum demand satisfied along the route turns out to be 1650. For those routes, where maximum link flow on the feeder route is less than 1650 passengers, smaller size mini buses need to be operated. These mini buses may also be operated on those routes where total length of narrow / congested road links along the feeder path is greater than one Km or the total length of narrow road links is more than 50 percent of the feeder route length.

Level of service is defined in terms of the maximum and minimum bus load along the route. Four different levels of service (LOS I – IV) identified for scheduling standard and Mini buses are given in Table 7.18.

Table 7.18: Level of Service for Scheduling Plan

Level of service	Standard Bus		Mini-Bus	
	Minimum bus Load	Maximum bus Load	Minimum bus Load	Maximum bus Load
I	30	50-60	15	25-30
II	35	60-70	17	30-35
III	40	65-75	20	32-37
IV	45	70-80	22	34-40

For each link of the network, the flow of passengers passing through the link is determined. The link nearest to the MRTS station will have maximum link flow and link touching the road terminal will have the minimum link flow. Thus weighted average link flow along with maximum link flow are also calculated for assigning the bus trips to a feeder route on the basis of minimum and maximum vehicle load for various levels of service. Round trip time for the route is calculated by considering the running speed, lay over time and halt time at stops. The average halt time at an intermediate stop taken in the study is 20 Seconds and the halt time at terminal is assumed as 60 seconds. The layover time at terminals during peak period and mid-day period is uniformly taken as 180 seconds. The operating headway, number of buses required, and various other characteristics of the scheduling plan are estimated.

The scheduling plan is prepared for each of the following alternative conditions given in Table 7.19.

Table 7.19: Alternative Conditions for Scheduling Plan

Alternative conditions	Levels
Time Period	Two levels (Peak-period and Mid-day period)
Desired levels of service	Four levels (LOS - I to LOS – IV)

7.7.1 Scheduling Characteristics for the Routes (Peak-period)

The results for the scheduling plan at LOS-I are presented in Table 7.20 for the peak period of operation. Three more tables corresponding to each of the three levels of service (LOS II to LOS-IV) are also generated for the scheduling results.

Scheduled time headways of operation for the 173 routes range between 3 to 20 minutes, with the number of bus trips in each direction varying between 60 and 9 respectively for the peak period of 3-hour duration. Number of buses required for the routes to operate the scheduled trips range between 3 and 35 for the highest level of service (LOS-I). 38 feeder routes are to be operated with Mini buses. Number of Parking lots required at the MRTS station / road terminal to operate the scheduled trips of different routes depend upon the specified layover time and the operating headway and are within the range of 1-2 for

Table 7.20: Scheduling Plan at Level of Service –I (Peak Period)

Rt. No.	MRTS station	Feeder route Terminal	Length (KM)	Trips	Head-Way (Min)	Park-ing lots	No. of buses	Total Wait time (Hrs)	Km per bus
1	BARWALA	Bawana Schl	11.4	10	18	1	4	85	57
2	BARWALA	Kanjhawla Mor	10	26	7	1	8	56	65
3	BARWALA	Rani Khera Mor	10	18	10	1	6**	28	60
4	BARWALA	Dal Mill (Holunki)	10.7	22	8	1	8	71	59
5	BARWALA	MCD Str Pooth Khurd	11.1	15	12	1	5	80	67
6	BARWALA	Sultanpur Vill	11.7	13	14	1	5	85	61
7	BARWALA	Madan Pur Dabas	9.5	16	11	1	5**	28	61
8	BARWALA	Rani Khera Mor	7.3	13	14	1	4**	30	48
9	BARWALA	Begum Pur	4.5	60	3	2	11	56	49
10	RITHALA	Badli Vill	7.1	12	15	1	4	82	42
11	RITHALA	Pira Garhi(Roh.Rd)	5.7	9	20	1	3	81	34
12	RITHALA	Mangol Puri Sch	6.6	26	7	1	7**	44	49
13	RITHALA	Mangol Puri R Blk	5.7	9	20	1	3	79	34
14	ROHINI WEST	Khera Kalan Schl	11.1	12	15	1	5	79	53
15	ROHINI WEST	Khera Garhi	10.6	12	15	1	4	67	64
16	ROHINI WEST	Krishan Vih	4.3	60	3	2	12	97	43
17	ROHINI WEST	Rohini B Blk Sec 18	4.3	20	9	1	4**	24	43
18	ROHINI EAST	Goodwill Kanta	11.1	22	8	1	9	70	54
19	ROHINI EAST	Qammaruddin Ngr Mor	10	13	14	1	5	84	52
20	ROHINI EAST	Jh Puri S.Bzr	6.9	20	9	1	6**	30	46
21	ROHINI EAST	Jahangirpuri (GT Road)	7.6	22	8	1	7**	43	48
22	ROHINI EAST	Sarai Pipal Thala	6.3	14	13	1	4**	43	44
23	ROHINI EAST	Shlm Vill	5.7	9	20	1	3**	31	34
24	PITAMPURA	Chand Ngr	12.4	26	7	1	12	74	54
25	PITAMPURA	Adhyapak Ngr	10.4	45	4	2	17	75	55
26	PITAMPURA	Jain Mandir GT Rd	10	26	7	1	10	83	52
27	PITAMPURA	M.B.S. Ngr	11.8	22	8	1	10	77	52
28	PITAMPURA	Khayala Desu Office	9.5	20	9	1	8	76	48
29	PITAMPURA	Jwala Heri	7.4	30	6	2	9	64	49
30	PITAMPURA	Sultan Puri AE Blk	8.5	26	7	1	9	79	49
31	PITAMPURA	Pasch Vih AO Blk	7.9	26	7	1	9	66	46
32	PITAMPURA	New Multan Ngr	8	26	7	1	9	65	46
33	PITAMPURA	DAV Schl S.Pur	5.8	22	8	1	6	75	42
34	PITAMPURA	Mangol Puri Sch	6.7	45	4	2	13	95	46
35	PITAMPURA	S.Gandhi Tpt Ngr	4.5	22	8	1	5	76	40
36	PITAMPURA	Mangol Pur Khurd	4.4	18	10	1	4	54	40
37	KOHAT ENCLAVE	M. Puri Mor (Ram Das	9.6	36	5	2	17	82	41
38	KOHAT ENCLAVE	Rajori Garden (NG RD)	9.3	20	9	1	9	81	41
39	KOHAT ENCLAVE	Rajori Garden R. Road	8.9	18	10	1	8	87	40

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40	KOHAT ENCLAVE	P.Puri Mkt	6.9	22	8	1	8	89	38
41	WAZIRPUR	Narayana Vih	11.3	22	8	1	12	87	41
42	WAZIRPUR	Narayana Vill	11.2	22	8	1	12	87	41
43	WAZIRPUR	JJ Colony. R Ngr	10	15	12	1	7	83	43
44	WAZIRPUR	Raghbir Ngr M. Blk	8.9	36	5	2	16	73	40
45	WAZIRPUR	Pasch Vih Janta Flats	6.8	13	14	1	5	85	35
46	WAZIRPUR	Tagore Park	6.5	60	3	2	20	100	39
47	WAZIRPUR	GTK Depot	5.7	60	3	2	18	81	38
48	WAZIRPUR	Jh Puri S.Bzr	5.6	60	3	2	18	117	37
49	WAZIRPUR	Haider Pur Vill	4.8	36	5	2	10	73	35
50	WAZIRPUR	Shlm Bagh Resv Off	4.4	26	7	1	6	81	38
51	KANAHYA NAGAR	Kripal Ashram	6.2	60	3	2	20	161	37
52	KANAHYA NAGAR	Gur Mandi	5.7	60	3	2	18	163	38
53	TRI NAGAR	Ashram (Hari Ngr)	11.4	45	4	2	26	91	39
54	TRI NAGAR	Central Jail	11.2	60	3	2	35	70	38
55	TRI NAGAR	Lajwanti Garden	11.1	60	3	2	34	68	39
56	TRI NAGAR	Lajwanti Garden	11.6	45	4	2	27	76	39
57	TRI NAGAR	Prem Ngr	10.5	45	4	2	25	85	38
58	TRI NAGAR	DDA Workshop	9.1	26	7	1	12	83	39
59	TRI NAGAR	Narayana Vill	8.7	22	8	1	10	84	38
60	TRI NAGAR	Raghbir Ngr S. Mandi	8.6	60	3	2	28	78	37
61	TRI NAGAR	Narayana Vih	8.8	16	11	1	8	86	35
62	TRI NAGAR	Cambridge School	8.3	36	5	2	16	81	37
63	TRI NAGAR	Naraina Vih	7.9	18	10	1	8	85	36
64	TRI NAGAR	Rajouri Garden Mkt	8.1	30	6	2	13	91	37
65	TRI NAGAR	Payal Cinema	6.4	14	13	1	6	87	30
66	TRI NAGAR	P Bagh Rd/85	6.4	45	4	2	16	72	36
67	TRI NAGAR	West Patel Ngr	4.4	45	4	2	15	66	26
68	VIVEKANANDA PURI	East Patel Ngr	4.7	60	3	2	21	107	27
69	VIVEKANANDA PURI	South P Ngr	4.6	60	3	2	21**	51	26
70	VIVEKANANDA PURI	Rajendar Ngr Mkt	4.6	60	3	2	21	137	26
71	VIVEKANANDA PURI	DTC Colony SPD	4.5	60	3	2	21**	55	26
72	ISBT	ITO BSZM	6.6	60	3	2	33	299	24
73	ISBT	Raj Ghat	4.3	60	3	2	16	78	32
74	SHASTRI PARK	Kotla Village	10.5	45	4	2	27**	50	35
75	SHASTRI PARK	Shashi Garden	9.1	22	8	1	11	88	36
76	SHASTRI PARK	Mayur Vih Mor	9.4	45	4	2	26**	47	33
77	SHASTRI PARK	Mother Dairy	8.8	22	8	1	11	87	35
78	SHASTRI PARK	Mother Dairy Mor	8.6	45	4	2	24**	45	32
79	SHASTRI PARK	Karwal Ngr Trmnl	8.1	60	3	2	27**	97	36
80	SHASTRI PARK	C.R.P.F. Camp	8.6	60	3	2	27**	69	38
81	SHASTRI PARK	Shakarpur	6.6	60	3	2	27**	44	29
82	SHASTRI PARK	ITO BSZM	6.7	45	4	2	18	55	34
83	SHASTRI PARK	Delite Cinema	5.3	26	7	1	9	50	31
84	SHASTRI PARK	Delhi Gate JLN Marg	5.2	45	4	2	15	41	31

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85	SHASTRI PARK	Rajeev Ngr	5.9	60	3	2	20**	66	35
86	SHASTRI PARK	Raj Ghat	4.6	16	11	1	4**	22	37
87	SHASTRI PARK	Geeta Colony	4.7	60	3	2	19**	31	30
88	GAUTAM PURI	Johri Pur Mor	6.6	60	3	2	22	78	36
89	GAUTAM PURI	Khajoori Mor	5.8	60	3	2	20**	76	35
90	GAUTAM PURI	G.M.S. Sec School	5.8	60	3	2	20	81	35
91	SEELAMPUR	New Kondli C.I.	12.4	60	3	2	43**	38	35
92	SEELAMPUR	New Kondli Market	11.4	60	3	2	39**	43	35
93	SEELAMPUR	Pratap Ngr	10.5	11	16	1	6	84	38
94	SEELAMPUR	Mayur Vih Phase II	10.3	16	11	1	10	80	33
95	SEELAMPUR	Trilok Puri Gurdwar	10.6	45	4	2	27**	48	35
96	SEELAMPUR	Pump House	9.6	9	20	1	5	79	35
97	SEELAMPUR	Shakar Pur Mor	5.8	22	8	1	9	64	28
98	SEELAMPUR	Yamuna Play Complex	5.5	36	5	2	12**	38	33
99	SEELAMPUR	Saini Enclave	4.8	14	13	1	5	59	27
100	SHAHDRA	Rama Garden	10.1	60	3	2	31**	75	39
101	SHAHDRA	Vikas Puri Mor	7.1	60	3	2	22	76	39
102	SHAHDRA	Johri Pur	6.8	60	3	2	23**	109	35
103	SHAHDRA	Sareshtha Vih	6.3	45	4	2	15	78	38
104	SHAHDRA	Dilshad Garden Govern	5.4	60	3	2	19**	90	34
105	SHAHDRA	New Seema Puri	6	60	3	2	22	84	33
106	SHAHDRA	Sanjay Ngr	5.7	60	3	2	20	79	34
107	SHAHDRA	Nand Nagri Depot	4.6	60	3	2	17	74	32
108	SHAHDRA	Mandoli Village	5.5	45	4	2	15	93	33
109	SHAHDRA	Nand Nagri	4.9	60	3	2	18	95	33
110	VISHVA VIDYALAYA	Nathu Pura Mor	9.8	45	4	2	18	81	49
111	VISHVA VIDYALAYA	Inder Cly	10.7	60	3	2	26	86	49
112	VISHVA VIDYALAYA	Adarsh Ngr	5.7	60	3	2	18	137	38
113	VISHVA VIDYALAYA	Gujranwala Town	4.9	60	3	2	17	76	35
114	OLD SECTT.	Jagat Pur Vill	7	20	9	1	6**	46	47
115	OLD SECTT.	Jharoda	6.6	20	9	1	6**	42	44
116	OLD SECTT.	Gandhi Vih	5.3	20	9	1	6**	42	35
117	OLD SECTT.	Nanak Sar	5.1	20	9	1	6**	41	34
118	OLD SECTT.	N. Vih (T)	4.3	22	8	1	6**	47	32
119	CIVIL LINES	RP Bagh DTC Cly	4.8	60	3	2	16	84	36
120	NEW DELHI	Kalyan Puri	10.1	60	3	2	30	86	40
121	NEW DELHI	Staff Quarters (M. Da	11.5	45	4	2	32	93	32
122	NEW DELHI	Mayur Vih Mor	9.4	60	3	2	29	83	39
123	NEW DELHI	P.P. Ganj	9.6	60	3	2	29	94	40
124	NEW DELHI	Mayur Vih (Phase	11.1	45	4	2	31	92	32
125	NEW DELHI	Mandevli	10.7	60	3	2	32	83	40
126	NEW DELHI	Pragathi Maidan Bh Rd	5.7	60	3	2	25	80	27
127	NEW DELHI	I.P. Depot	5.5	60	3	2	17	77	39
128	NEW DELHI	Patyala House	4.3	60	3	2	16	77	32

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129	CONNAUGHT PLACE	Pandav Ngr	10.3	45	4	2	27	100	34
130	CONNAUGHT PLACE	Preet Vih	8.9	45	4	2	22	89	36
131	CONNAUGHT PLACE	Subziwala Chok	5.1	60	3	2	21	84	29
132	CONNAUGHT PLACE	DB Gupta Mkt	4.6	20	9	1	8	90	23
133	PATEL CHOWK	Narayana Vill	11.1	10	18	1	6	85	37
134	PATEL CHOWK	Narayana Vih	10.7	11	16	1	7	84	34
135	PATEL CHOWK	Siriniwas Puri	10	30	6	2	14	62	43
136	PATEL CHOWK	Maharani Bagh – Woman P	9.5	45	4	2	20	57	43
137	PATEL CHOWK	Nehru Ngr	10.4	30	6	2	14	66	45
138	PATEL CHOWK	Inder Puri A. Blk	9.5	10	18	1	6	82	32
139	PATEL CHOWK	Agricultural res ins.	9.4	9	20	1	4**	27	42
140	PATEL CHOWK	Jangpura Extn	7.9	20	9	1	8	59	40
141	PATEL CHOWK	Parshad Ngr	5.9	14	13	1	5**	44	33
142	PATEL CHOWK	Budha Park	6.8	10	18	1	4**	40	34
143	PATEL CHOWK	CGO Complex (T)	5.4	20	9	1	5	56	43
144	PATEL CHOWK	National physical lab.	6.5	10	18	1	4**	39	32
145	CEN. SECTT.	I.A.F Colony	10.1	15	12	1	7	68	43
146	CEN. SECTT.	Bentex	11.7	36	5	2	19	68	44
147	CEN. SECTT.	N.I.H.family welfare	11.3	36	5	2	18	71	45
148	CEN. SECTT.	Krishna Market	11.7	60	3	2	30	80	47
149	CEN. SECTT.	Military Hosp	12	13	14	1	7	73	45
150	CEN. SECTT.	Bair Sarai	12.3	45	4	2	24	73	46
151	CEN. SECTT.	Vasant Lok E Marg	10.4	30	6	2	14	77	45
152	CEN. SECTT.	Mt St. Mary School	11.7	22	8	1	11	67	47
153	CEN. SECTT.	Vasant Vih E Blk	10.5	20	9	1	9	67	47
154	CEN. SECTT.	Panchsheel Club	10.8	30	6	2	15	76	43
155	CEN. SECTT.	Central School	10	45	4	2	21	49	43
156	CEN. SECTT.	R.R.Lines Cantt	8.6	15	12	1	6	67	43
157	CEN. SECTT.	R.T.R Colg	8.4	13	14	1	5	61	44
158	CEN. SECTT.	Bentex	8.5	11	16	1	6**	41	31
159	CEN. SECTT.	S.M. Temple	9.7	12	15	1	5	68	47
160	CEN. SECTT.	Pratap Chowk	8.2	15	12	1	6	63	41
161	CEN. SECTT.	Mohan singh market	9.0	60	3	2	24	48	45
162	CEN. SECTT.	S.J. Enclave	8.2	20	9	1	7	56	47
163	CEN. SECTT.	R.R. Line Cantt	9.2	16	11	1	7	62	42
164	CEN. SECTT.	S.J. En. (T)	9.2	26	7	1	11	66	43
165	CEN. SECTT.	R.K. Puram Sector 8	8.8	12	15	1	5	86	42
166	CEN. SECTT.	Sarojni Ngr P.S.	8.5	16	11	1	6	75	45
167	CEN. SECTT.	Sewa Ngr Bridge	7.1	14	13	1	5	64	40
168	CEN. SECTT.	Saroji Ngr Mkt	7.5	26	7	1	9	56	43
169	CEN. SECTT.	JLN Stadium	7.3	16	11	1	6	69	39
170	CEN. SECTT.	Simon Bolivar Marg	6.7	10	18	1	4	81	34
171	CEN. SECTT.	INS House	5.3	20	9	1	6	48	35
172	CEN. SECTT.	Dayal Singh Colg	5.5	16	11	1	5	53	35
173	CEN. SECTT.	Bharti Ngr	4.3	10	18	1	3	82	29

** MINI BUS

various routes. A fleet of 2396 buses is required for all the 173 routes to be operated at the first level of service (LOS-I). The bus Km. operated by a route depends upon the number of scheduled trips, the route length and the number of buses. This vehicle operating distance has large variation among the 173 routes.

7.7.2 Scheduling Characteristics for MRTS Stations (Peak-period)

The various scheduling parameters of the routes are aggregated for each MRTS station to determine the operating characteristics. The scheduling characteristics of the feeder routes on various stations are presented in Table 7.21. The daily passenger demand satisfied by the feeder routes at various MRTS stations ranges between 9500 and 129500. Buses required at MRTS stations to serve the different feeder routes are presented for three levels of service (LOS – I, II and III). For the first level of service (LOS – I), more than 200 buses are required at five MRTS stations to operate feeder routes. These MRTS stations are Shadara, New Delhi, Shastri Park, Tri Nagar and Central Secretariat, which require 202, 241, 265, 279 and 301 buses respectively. Some of the MRTS stations require as low as 15 buses for operating the feeder routes at different LOS. Number of parking lots needed to handle the buses at the MRTS station range between 4 and 37.

7.7.3 System Operating Characteristics (Peak Period)

The system operating characteristics for the feeder route system during the peak period are presented in Table 7.22 for the four levels of service (LOS I – IV).

The total passenger demand for feeder routes during 3-hour duration of peak period turns out to be 306098. As the level of service deteriorates, the fleet size required for all the 173 routes decreases and the total passenger waiting time increases. A fleet of 2396 buses at LOS-I decreases to 2134 buses at LOS-II, which further reduces to 1989 buses at LOS-III. The minimum fleet size of 1879 buses is required at LOS-IV. The total passenger waiting time increases from 12626 hours at LOS-I to 16422 hours at LOS-IV, an increase of 30 percent. The average waiting time increases from 2.5 minutes to 3.2 minutes, as the LOS-I changes to LOS-IV. To judge the vehicle utilization, Km. operated per bus is

estimated for the period of operation. Results show that for peak period of 3 hours, on an average each bus is operated for 38 km. The total operating cost for the bus system is determined considering an operation cost of Rs. 15 per Km. The operation cost per passenger is estimated and found to be Rs 2.24 for LOS-I and Rs 1.72 for LOS-IV.

Table 7.21: Characteristics of Feeder Routes on MRTS Stations (Peak-period)

MRTS Station	Station daily pass. demand for feeder routes	No. of feeder routes	Level of service					
			LOS – I		LOS – II		LOS – III	
			Buses	Park -ing lots	Buses	Park -ing lots	Buses	Park -ing lots
BARWALA	29000	9	56	10	51	10	47	10
RITHALA	9500	4	17	4	15	4	15	4
ROHINI WEST	21600	4	25	5	23	5	22	5
ROHINI EAST	13600	6	34	6	31	6	29	6
PITAMPURA	71000	13	121	16	111	16	95	15
KOHAT ENCLAVE	21600	4	42	5	38	5	34	4
WAZIRPUR	83900	10	124	15	111	15	105	13
KANAHYA NAGAR	51900	2	38	4	38	4	38	4
TRI NAGAR	118100	15	279	25	240	24	211	23
VIVEKANANDA PURI	56000	4	84	8	84	8	84	8
ISBT	60200	2	49	4	45	4	45	4
SHASTRI PARK	92500	14	265	24	259	24	235	24
GAUTAM PURI	37600	3	62	6	52	6	52	6
SEELAMPUR	36300	9	156	13	130	13	126	12
SHAHDRA	129500	10	202	20	179	20	174	20
VISHVA VIDYALAYA	57600	4	79	8	66	8	66	8
OLD SECRETARIAT	11900	5	30	5	27	5	25	5
CIVIL LINES	13400	1	16	2	16	2	16	2
NEW DELHI	115100	9	241	18	205	18	186	18
CONNAUGHT PLACE	40900	4	78	7	68	7	67	7
PATEL CHOWK	34600	12	97	15	84	13	80	13
CENTRAL SECRETARIAT	118900	29	301	37	261	35	237	34

Table 7.22: System Operating Characteristics (Peak period)

Period pass. Demand for feeder routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
306098	I	2396	91472	38	2.24	12626	2.5	25	52
	II	2134	80755	38	1.98	14287	2.8	28	59
	III	1989	75043	38	1.84	15382	3.0	30	63
	IV	1879	70059	37	1.72	16422	3.2	32	67

7.7.4 Scheduling Characteristics for the Routes (Mid-day period)

The scheduling plan of the feeder route system for the mid day period of 6 hour duration is also generated under the four different levels of service (LOS-I to LOS–IV). The total passenger demand for feeder routes during 3-hour duration of mid day period turns out to be 379562 (Table 7.23). As the level of service deteriorates, the fleet size required for all the 173 routes decreases and the total passenger waiting time increases. A fleet of 1713 buses at LOS-I decreases to 1569 buses at LOS-II, which further reduces to 1467 buses at LOS-III. The minimum fleet size of 1378 buses is required at LOS-IV. The total passenger waiting time increases from 21914 hours at LOS-I to 27257 hours at LOS-IV, an increase of 24.4 percent. The average waiting time increases from 3.5 minutes to 4.3 minutes, as the LOS-I changes to LOS-IV.

Table 7.23: System Operating Characteristics (Mid-day period)

Period pass. Demand for feeder routes	Level of service	Fleet size	Total bus-km operated	Km. Per bus	Operation cost per passenger (Rupees)	Total pass. Wait time (hour)	Av. Waiting time (min)	System operating loads	
								Avg. bus load	Max. bus load
379562	I	1713	128508	75	2.54	21914	3.5	22	45
	II	1569	117247	75	2.32	24089	3.8	24	49
	III	1467	109013	74	2.15	25868	4.1	25	53
	IV	1378	102416	74	2.02	27257	4.3	27	57

The scheduling characteristics of the feeder routes during mid-day period on various stations are presented in Table 7.24. The highest number of 173, 201 and 212 buses are required to operate feeder routes for the MRTS stations at Shastri Park, Tri Nagar and Central Secretariat respectively at LOS-I. Only 10 buses are required for operating the feeder routes at LOS-II and LOS-III for Civil Lines MRTS station. Number of parking lots needed to handle the buses at the MRTS station range between 4 and 32.

Table 7.24: Characteristics of Feeder Routes on MRTS Stations (Mid-day Period)

MRTS Station	Station daily pass. demand for feeder routes	No. of feeder routes	Level of service					
			LOS – I		LOS – II		LOS – III	
			Buses	Park -ing lots	Buses	Park -ing lots	Buses	Park -ing lots
BARWALA	29000	9	43	10	42	10	39	10
RITHALA	9500	4	15	4	14	4	14	4
ROHINI WEST	21600	4	24	5	24	5	21	5
ROHINI EAST	13600	6	27	6	25	6	25	6
PITAMPURA	71000	13	79	15	71	13	66	13
KOHAT ENCLAVE	21600	4	27	4	26	4	25	4
WAZIRPUR	83900	10	89	13	81	13	72	12
KANAHYA NAGAR	51900	2	38	4	38	4	38	4
TRI NAGAR	118100	15	173	22	152	17	140	15
VIVEKANANDA PURI	56000	4	79	8	69	8	61	8
ISBT	60200	2	41	4	41	4	40	3
SHASTRI PARK	92500	14	201	23	186	19	176	19
GAUTAM PURI	37600	3	45	6	41	6	39	4
SEELAMPUR	36300	9	102	12	91	10	90	10
SHAHDRA	129500	10	151	19	144	17	129	15
VISHVA VIDYALAYA	57600	4	54	7	48	6	43	6
OLD SECRETARIAT	11900	5	20	5	20	5	19	5
CIVIL LINES	13400	1	12	2	10	2	10	2
NEW DELHI	115100	9	148	18	130	16	119	13
CONNAUGHT PLACE	40900	4	51	7	42	5	42	5
PATEL CHOWK	34600	12	82	13	75	12	72	12
CENTRAL SECRETARIAT	118900	29	212	32	199	31	187	30

7.7.5 Scheduling Characteristics for the System

It is observed from the results that for peak period, a total fleet of 2396 buses is required at the highest level of service (LOS-I). For the level of service-IV, the required fleet size is only 1879 but it provides a poor level of service, average and maximum bus loads being 32 and 67 respectively. During mid day period (11 A.M. to 5 P.M.), the fleet size required for the LOS-I, is only 1713 buses being 71.5 percent of the fleet required for the peak period.

The total fleet size to be commissioned will be based on the requirement for the peak period. During the peak period of 3 hours, the buses operate on an average about 38 km, while for the mid day period of 6 hours, the average operating distance is of the order of 75 km. The average passenger waiting time for the best level of service (LOS-I) is 2.5 minutes for the peak period and 3.5 minutes for mid day period. This passenger waiting time increases with the deterioration of the level of service, being 3.2 minutes for the peak period and 4.3 minutes for the mid day period at the poor level of service (LOS-IV). The total operating cost for the bus system is determined considering an operation cost of Rs. 15 per Km. For the peak period, the operation cost per passenger is estimated to be Rs 2.24 for LOS-I and Rs 1.72 for LOS-IV. The bus operation cost for each passenger is found to be higher during the mid day period, being Rs 2.54 compared to Rs 2.24 for the peak period.

7.8 RESTRUCTURING OF EXISTING BUS ROUTES

Introduction of a Mass Rapid transit system in a metropolitan city facilitates the commuters to travel at a faster pace along the major corridors of the city. The existing bus routes running parallel to the MRTS corridors within a certain lateral distance have to compete with MRTS for their existence. Such routes, if allowed to remain in operation even after the commissioning of MRTS will nullify the very objective of providing MRTS in a metropolitan city. MRTS being operationally efficient and environmentally

beneficial will make these routes redundant. Restructuring of routes has to be affected within a lateral band of MRTS through curtailment, or deletion. But as restructuring of existing bus routes may invite public reaction, therefore a sensitivity analysis is to be carried out on the parameters involved in the identification of overlapping routes.
The deciding parameters for restructuring may be considered as

- Bandwidth parallel to the MRTS corridor
- Minimum overlapping length of routes
- Minimum ratio of overlapping distance to the total route length

Table 7.25 presents the number of overlapping routes under four different cases. The minimum overlapping distance is kept constant at 5 km for all cases. Only two parameters – bandwidth and the ratio of overlapping distance (the distance for which the route is traveling in the established band) to total route length, are varied. The number of overlapping routes increases as the bandwidth increases. Further as the ratio of overlapping distance to the route length increases, the number of overlapping routes decreases.

For a bandwidth of 1 Km and minimum overlapping length of 5 Km, the number of overlapping routes reduces from 58 to 19 if the ratio of overlapping distance to total route length is increased from 0.3 to 0.5. The results indicate that the number of overlapping routes vary considerably with bandwidth. When the ratio of overlapping distance to total route length is 0.3, the number of overlapping routes are 197 for a bandwidth of 2 Km as compared to 58 overlapping routes for a bandwidth of 1 Km. Similarly when the ratio of overlapping distance to total route length is 0.5, the number of overlapping routes increases from 19 in case of 2 km bandwidth to 108 for 1 km bandwidth.

There is thus a great need to restructure the existing bus network with the implementation of MRTS corridors. The suggested methodology, which also has a graphical interface, can be adopted by the user to restructure each of the identified overlapping route.

Table 7.25: Impact of Band Width on Identification of Overlapping Routes

Parameter	Case-I	Case-II	Case-III	Case-IV
Minimum Overlapping distance (Km)	5	5	5	5
Ratio of overlapping distance to total route length	0.3	0.3	0.5	0.5
Band width (meters)	1000	2000	1000	2000
Number of overlapping routes	58	197	19	108

7.9 INTEGRATION OF FEEDER BUS TRANSIT SYSTEM WITH GIS INTERFACE

Application of models for feeder bus transit system applied to the MRTS network of New Delhi involves the spatial and non-spatial database. The GIS interface presents the map of New Delhi through successive digital layers. The first digital layer is the outcome of location details from Bus stops, intersection points and MRTS stations. The second layer represents the road network links and MRTS links. Existing bus routes are superimposed on the road network and optimally generated feeder routes from optimization models are plotted on the map.

ARCVIEW 3.1 (GIS tool) package from Environment System Research Institute, USA (ESRI) is used for integrating the Decision support system of feeder bus transit network. Avenue programming facilitates the conversion of output data files from optimization models to shape files and the final outcome is in the form of maps on Arc-view platform. Queries related to Bus stops, MRTS station, Road and MRTS network, Existing bus routes, feeder routes, overlapping routes parallel to the MRTS corridor and restructured route characteristics can be obtained on the Arc-View platform and is shown in Figures 7.13 to 7.18.

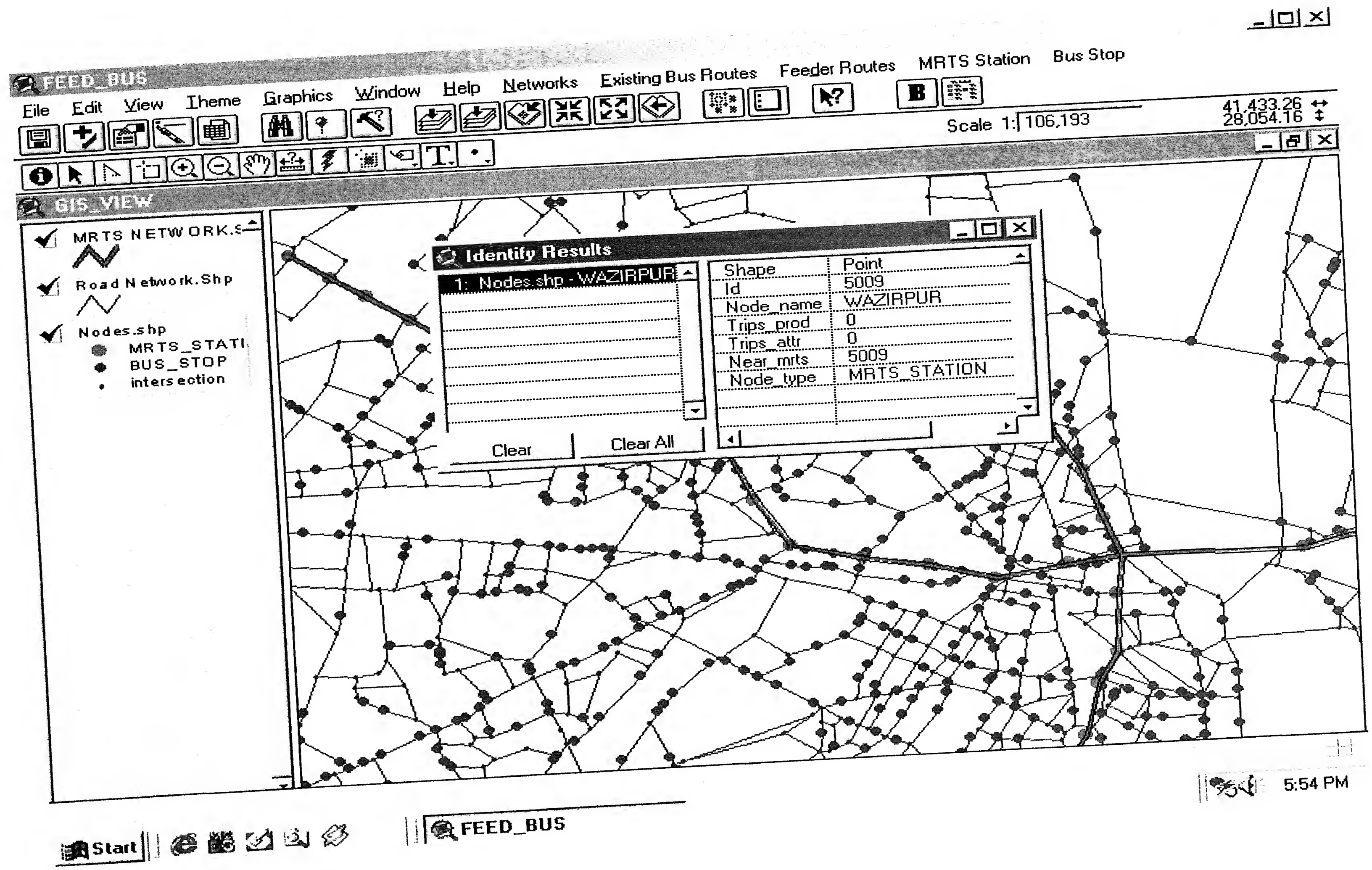

Figure 7.13: Query for MRTS Station

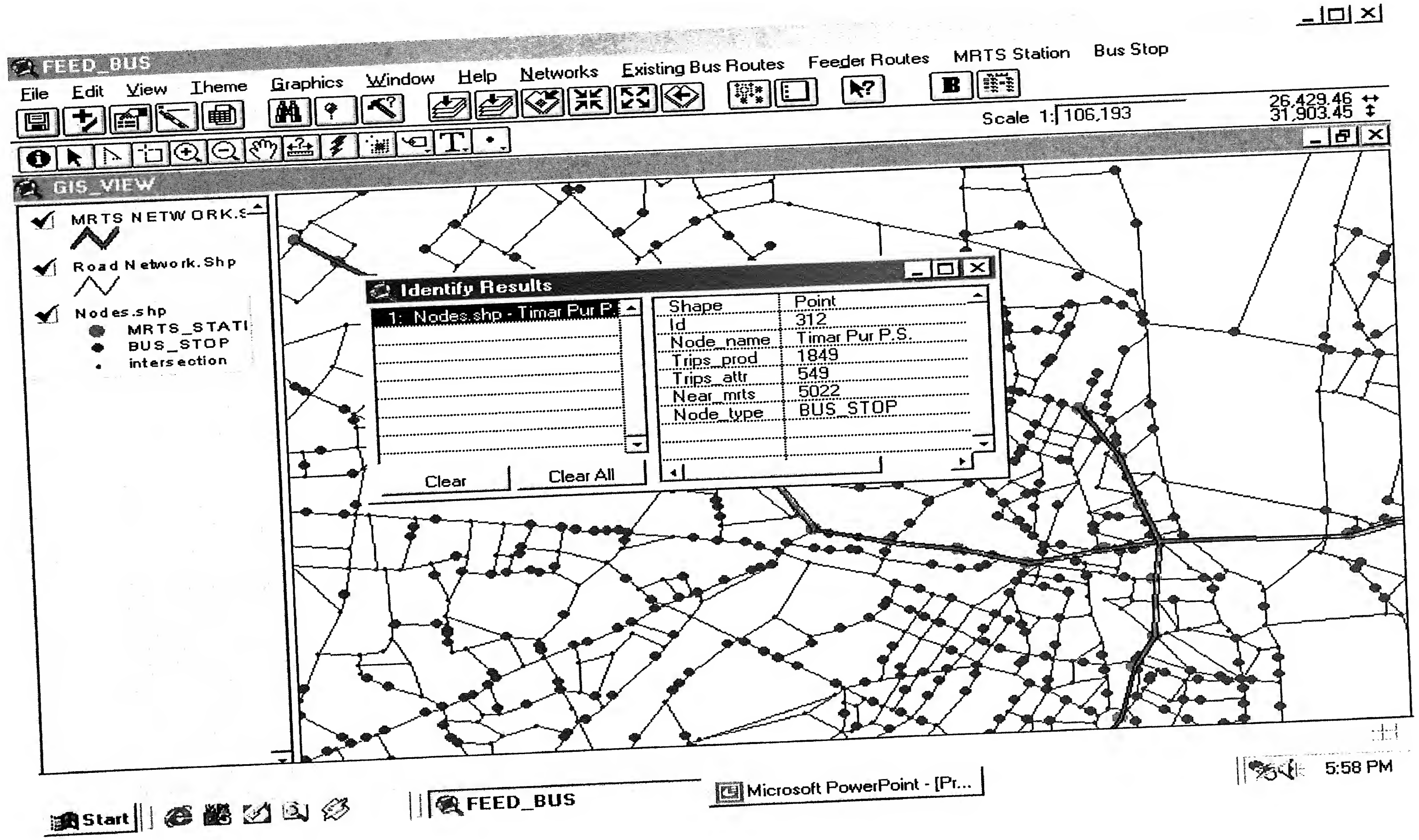

Figure 7.14: Query for Bus Stop

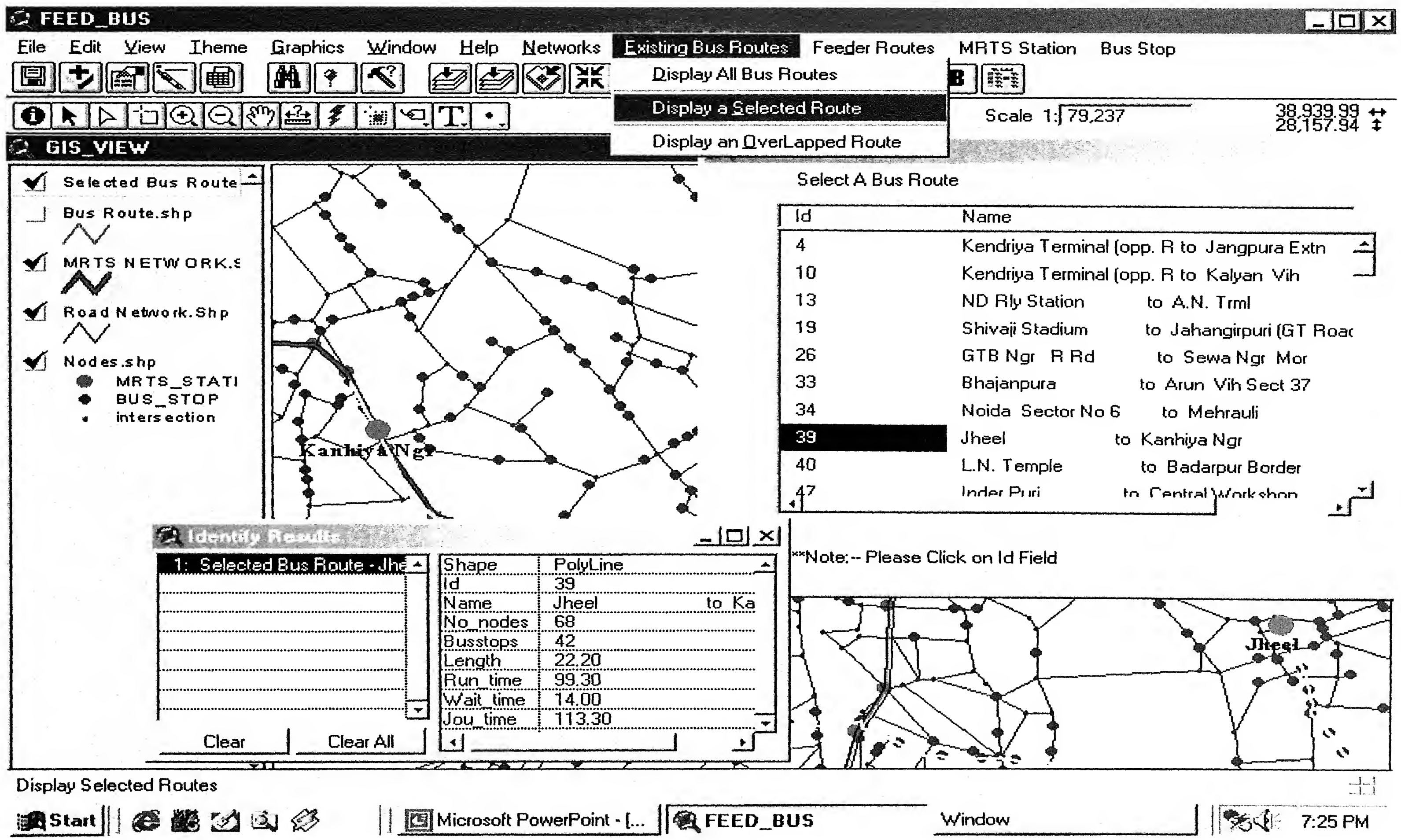

Figure 7.15: Query for a Selected Route

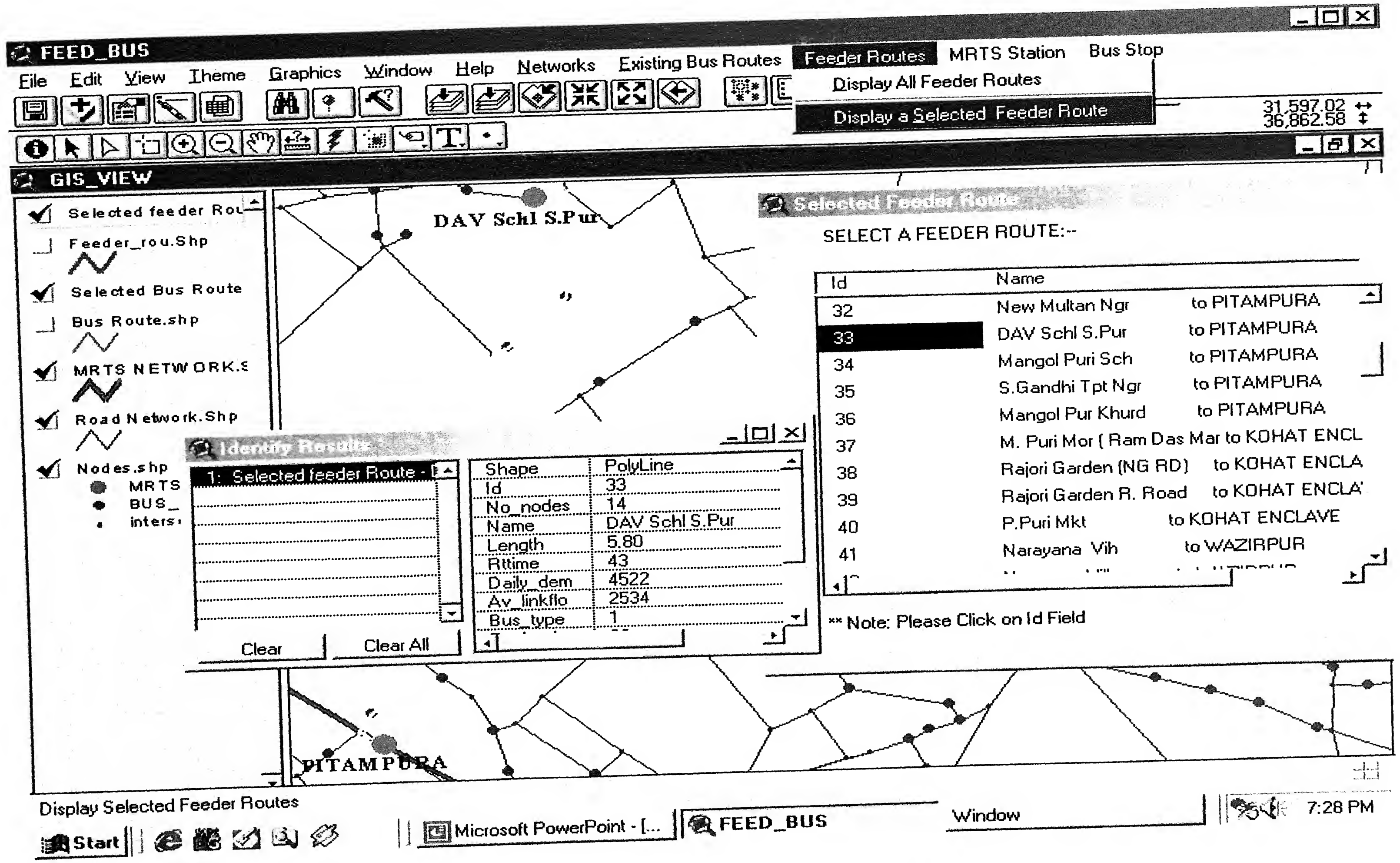

Figure 7.16: Description of a Feeder Route

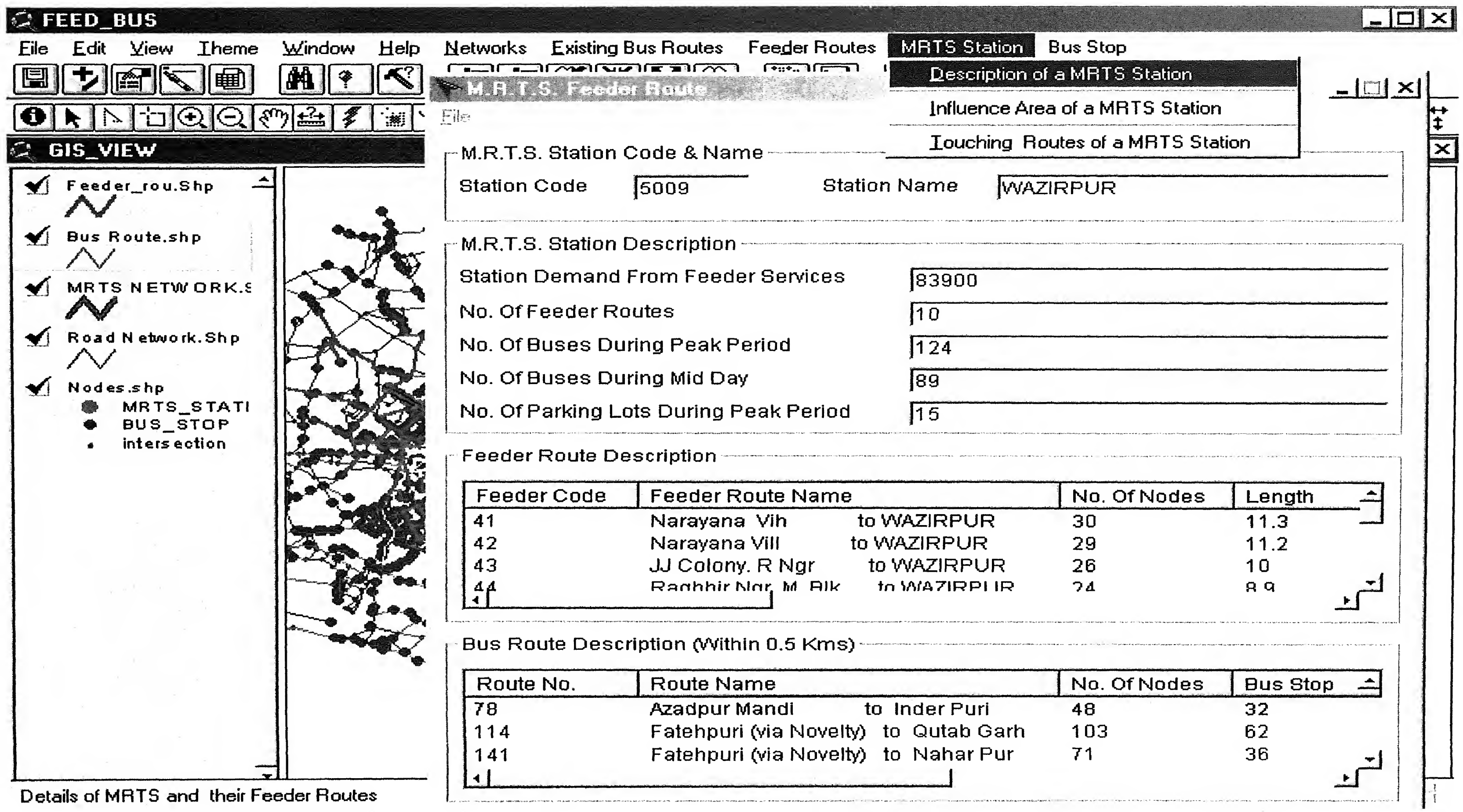

Figure 7.17: Description for MRTS station

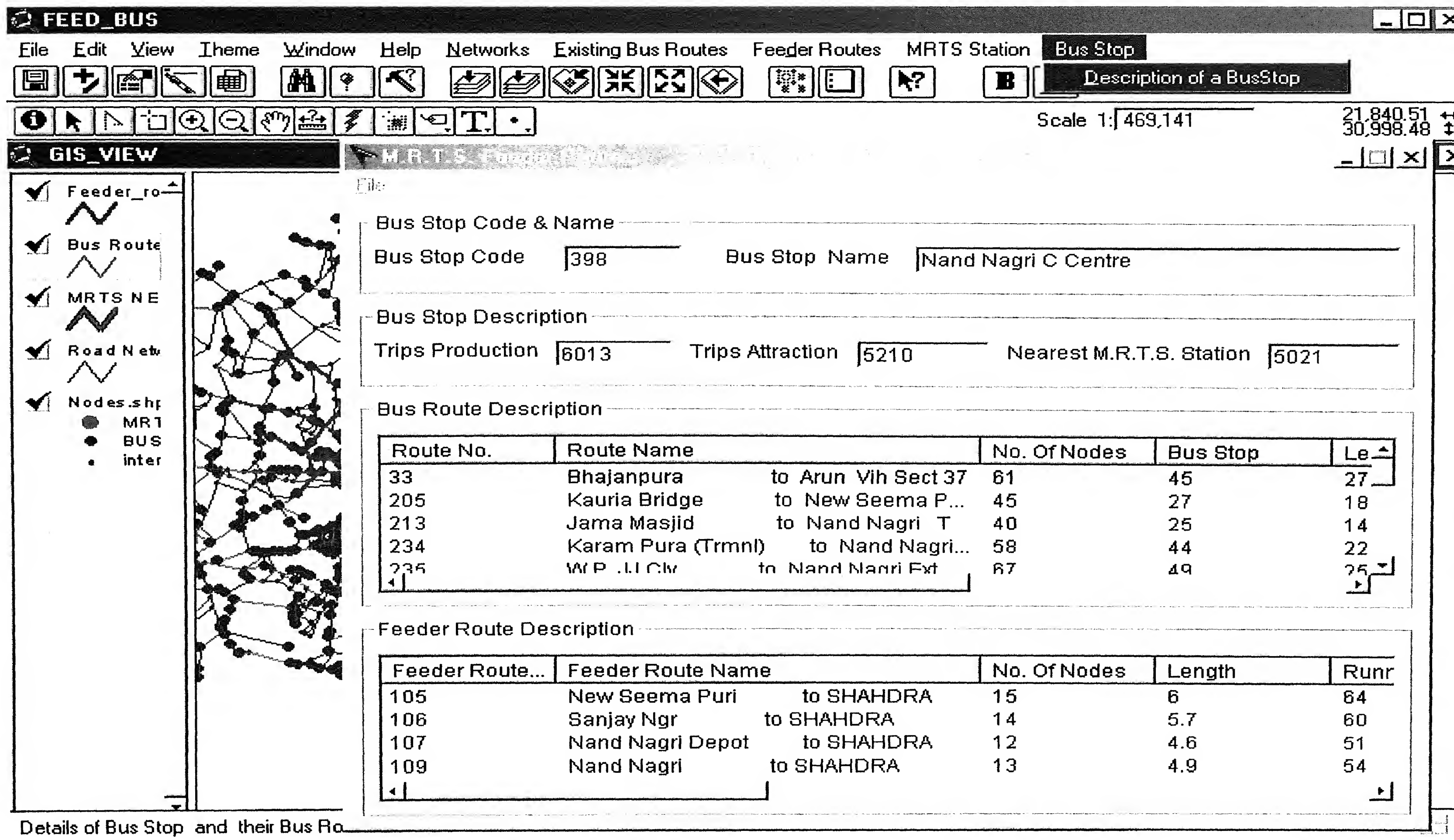

Figure 7.18: Description of Bus stop

7.10 SUMMARY

In this chapter, a 'Decision Support System' is developed for Delhi mass rapid transit system. To start with, since the MRTS does not presently exist, the coefficients of parameters for travel time and travel cost is estimated based on the modal split for public transport in Delhi. To test the sensitivity of the mode choice model with respect to different parameters and decision thresholds, the various parameters, which are of considerable importance, are studied under different scenarios. Station demand is calculated for each MRTS station. Influence area for each MRTS station is demarcated through three different techniques and the results obtained from mode choice analysis are considered to be the most appropriate. Feeder routes are generated for each MRTS station separately. Sensitivity analysis has been conducted on meandering factor and minimum distance constraint between terminals for generating feeder routes. Scheduling of buses is made for three periods of the day namely morning peak, mid day and evening peak period. Minimum policy headway is defined based on operational constraints. Four different levels of service (LOS I – IV) are identified for scheduling of standard and mini buses. The results obtained from different model are integrated with geographical information system and is presented on Arc-view platform.

CHAPTER 8

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

8.1 SUMMARY

The primary objectives of this study has been

(i) To evolve a methodology for design of Bus Transit Network for large cities based on Hub and Spokes System.

(ii) To develop a Decision Support System for routing, scheduling of feeder bus routes for Mass Rapid Transit System and to restructure the existing bus routes.

The above objectives involved development of a series of models and the developed systems are applied to New Delhi, the capital city of India. The public transport system of Delhi is primarily road based catering to a daily demand of about 7.7 million passengers. The existing bus transit network, spread over a road length of 1650 Km, has over 1100 bus routes with an operating fleet of over 7000 buses. A new MRTS network for Delhi, covering a route length of 33 Km, is under construction to ease out the public transport problems.

8.1.1 Methodology for Planning of Bus Transit Network of Large Cities

With the rapid urbanization in the recent past, the cities are developing away from the central business district (CBD) area. The 'Destination oriented design' methodology results in very long bus routes and to satisfy the desired demand pattern due to the haphazard development of cities in all directions away from the CBD area, a very large

number of bus routes are evolved. These zig-zag routes overlap on certain corridors resulting in bunching on various sections of the network. Hub and spokes system, which combines the traditional 'Destination oriented' approach along with 'Direction-oriented' approach, is ideally suited for such type of large networks. The important components of the system are: Hubs, Influence Area of Hubs, Inter-Hub routes and Secondary routes. The design methodology for planning of Hub and Spoke bus transit network design involves the following stages.

(i) Selection of Optimal hubs and Delineation of Influence area for each hub
(ii) Estimation of Inter-hub and Intra-hub demand
(iii) Generation of the path for Inter-hub routes
(iv) Generation of the path for Secondary routes
(v) Determination of service frequencies for Inter-hub routes
(vi) Determination of service frequencies for Secondary routes

Due to the complexity of the problem and large number of constraints, it may not be possible to obtain the global optimum for large transit network; heuristic models are therefore involved in the design process. Optimal selection of hubs is the backbone of Hub and Spokes bus transit system and is attempted through a mathematical model with the objective to minimize the 'Total Passenger Time' for the bus transit system. The location of optimal hubs is obtained by the following three-step procedure.

(i) Partitioning of stops in clusters
(ii) Location of hub within a cluster and its influence area
(iii) Selection of optimal hubs

As the transit network of a metropolitan city area consists of a large number of stops, the first step therefore partitions all the stops of transit network into a number of clusters. Each cluster will have a number of stops and one of them will be a Hub. The area enclosing the stops within a cluster defines the Influence area of the Hub. Two clustering methods are introduced in this study to partition the stops into a predefined number of clusters. One method 'Fuzzy-c-means clustering' belongs to the class of fuzzy logic and the other 'Self-organizing-map' is chosen from the neural networks. These clustering

methods offer generalized procedure for computing the clusters centers and stops present in the clusters.

Fuzzy-c-means clustering method and Self-organizing-map method partition the stops of the large city network into a number of clusters, each cluster representing some geographical area of the city. Hub is to be located in each cluster from the stops present in the cluster. This is achieved with the objective to minimize the 'Total Travel Distance' (Passenger-km) for all stops within a cluster. Due to the computational complexity for a large network in a metropolitan area, an algorithmic approach is applied for the location of hubs within a selected cluster. The third step evaluates the total passenger time for the transit network and the set of clusters, which provides the minimum 'Total Passenger Time', is treated as the optimal clusters/hubs for the bus transit network.

Two types of routes, Inter-hub routes and Intra-hub routes (spoke/secondary routes) are generated for the bus transit network. For this purpose, the inter-stop demand matrix is adjusted to estimate the inter-hub demand matrix and intra-hub demand matrix.

Inter-hub route generation model generates the inter-hub routes, which are reasonably direct, having high frequency and high operating speed of the buses. Inter-hub demand matrix heavily guides the inter-hub route identification. The terminal hubs are selected based on certain constraints of minimum inter-hub demand and minimum and maximum route length. Terminal hubs are first connected to each other along the shortest path. Alternative paths are generated between the terminal hubs through meandering along the shortest path. These alternative paths are evaluated such that the stops/hubs along the generated routes are served in an optimal way. The alternative paths are short listed using a criterion of 'Route Utilization Coefficient' and the final selection of optimal path is done on the basis of 'Desire passenger-km per km'.

In the model for generation of intra-hub routes, the secondary routes are generated within the influence area of hubs. Identification of two terminals, between which the paths of secondary routes are to be established are firstly identified. Shortest path is generated

between the identified terminal and the hub or between the two terminal stops. The area in the vicinity of shortest path is searched through meandering to generate the alternative paths. An alternative that maximizes the 'Desire-passenger-km per km' is taken as the optimal path for the secondary route.

The number of bus trips to be operated for a route depends upon the demand served along the route and the passenger flow on various links of the route. The demand served along the route can give only little idea about the desired bus trips, as some inter-nodal demand may be shared by more than one route. The passenger flow on the link of a route helps to determine the bus trips needed on a route, as the link may have a number of overlapping routes passing over it. To estimate the optimal bus trips for a route, an iterative heuristic algorithm is adopted in the scheduling model, the steps of which are enumerated below.

(i) Estimation of passenger flow on each link
(ii) Determination of desired trips for each link
(iii) Assignment of minimum trips for each route
(iv) Estimation of additional trips on each route
(v) Revised trips on each route of transit network

It starts with the estimation of passenger flow on each link of the transit network. The desired trips for each link is determined on the basis of passenger link flow on each link and the desired average bus load for a specified level of service. Minimum trips, which are required to each route is estimated by considering the weighted equivalent peak hours for the day and policy headway in the first iteration. Additional bus trips required on each link are determined. Minimum of the proportional bus trips for a route on the link is considered as the additional trips on the route. Revised bus trips on each route of the transit network are determined. The determination of revised bus trips for a route completes one-iteration of the model. In the next iteration, these revised bus trips act as the assigned bus trips and process is repeated. Additional bus trips are again determined for all the routes. This iterative process is continued till no more additional bus trips are required on each route. The operating headway, number of buses and round trip time for each route is determined and system characteristics are estimated.

The number of bus trips on a secondary route primarily depends on the maximum link flow. But there may be considerable variation of passenger flow on the various links along the route. Weighted average link flow is therefore also taken into consideration in determining the bus trips. The bus trips obtained from the maximum link flow and weighted average link flow are compared and optimal value of bus trips are assigned to the secondary routes. The round trip time for a route is estimated and the required headway subject to the minimum and maximum constraints of headway for operation of buses is estimated. The trips operated in each direction are calculated and the total fleet size is estimated. The operational characteristics are obtained for all the secondary routes and finally the characteristics of the system are estimated.

8.1.2 Decision Support System of Feeder Bus Routes for Rapid Transit System

A decision support system (DSS) is developed to prepare optimal routing and scheduling plan of feeder bus routes for an MRTS and to restructure the existing bus route network. This interactive DSS has a series of Heuristic optimization models integrated with geographical information system (GIS) environment, is user friendly, capable of handling large network, and has been implemented for Delhi. The broad study methodology for the system has the following important stages.

- Study of existing road network, existing bus transit system and proposed MRTS network.
- Mode-choice analysis to estimate the passenger demand matrix for combined MRTS and feeder network.
- Models for delineation of Influence Area for each MRTS station of the network
- Planning of feeder bus route network for the proposed MRTS network.
- Preparation of scheduling plan for the generated feeder bus system.
- Approach to restructure the existing bus route network in the light of MRTS and feeder bus routes.

Generation of comprehensive database is highly important for successful implementation of the study methodology. The data required for the study relate to:

- Inventory of road network Characteristics
- Inventory of existing bus route Characteristics
- Inventory of MRTS network Characteristics

Planning of feeder services require data at the disaggregate level (i.e. at bus stop level) to represent the true picture. This daily demand matrix and its distribution over different periods can be generated from the primary surveys to be conducted at the bus stops.

For the feeder bus services to high capacity transit system, the first step is to predict the demand on Mass Rapid Transit System, which is carried out through mode choice analysis. Logit model has been considered to split the travel demand between existing bus transit system and the MRTS. Travel time and travel cost for each node pair for both public transport modes is required to calculate their utility measures. Inter-stop travel time through existing bus routes is determined by taking care of zero transfer, one transfer and two transfer routes. In the beginning, if the MRTS does not exist, it may not be possible to clearly judge the nearest possible MRTS stations in the vicinity of origin or destination. An approach has, therefore, been devised to determine the best path through MRTS. Accessibility of the various inter-node transfers with respect to the MRTS is determined through two incidence matrices. The travel cost in case of buses on bus transit network and feeder routes is generally in the form of unit rate per kilometer or slab system. The travel cost between the MRTS stations can be taken up on unit rate basis or slab system. Different combinations have therefore been suggested for the travel cost. The operational constraints adopted for the mode choice model are:

(i) Maximum distance from the origin or destination to the MRTS station from where demand can be attracted and feeder routes are to be generated should be within a certain limit.

(ii) The distance traveled on MRTS corridor should be at-least some proportion of the total distance traveled between the origin and destination nodes.

(iii) The distance traveled on the MRTS corridor is greater than a certain minimum distance.

(iv) Availability of feeder routes on one end or both ends.

(v) Availability of limited existing bus routes or unlimited bus routes.

Considering the above operational constraints, the mode choice analysis estimates the share of demand between the bus transit network and MRTS/feeder bus service for each O-D pair. The connectivity matrices and share matrix are estimated. The inter MRTS station demand and station loads are calculated.

Each MRTS station has a certain geographical area from which trip makers will approach to the MRTS station. This area, termed as the Influence Area of an MRTS station, depends upon the estimated travel demand from the stops to the MRTS station and the geographical layout of stops with respect to the MRTS station. Three models named Heuristic Model, Fuzzy Model and Neural Network Model have been evolved to demarcate the influence area of each MRTS station. Heuristic model for the demarcation of Influence areas is based on the micro-details of each inter-nodal transfer of demand through the MRTS system. Demarcating of influence areas by Fuzzy model involves the fuzzy-c-means clustering algorithm whereas the Neural Network model uses the Self-organizing map algorithm.

Proper physical integration of MRTS and road network necessitates the generation of feeder route paths within the influence area of all MRTS stations. In the proposed routing model, feeder routes are generated separately for each MRTS station and the process is repeated to obtain the feeder routes for all stations of the MRTS network. The steps involved in generating an optimal path of a feeder route for an MRTS station are

i. Identification of bus terminal within the influence area of MRTS station
ii. Generation of alternative paths between bus terminal and MRTS station
iii. Evaluation of alternative paths and selection of optimal path.

The feeder bus system has to serve all the nodes/stops in the influence area of an MRTS station. One end of a feeder route path is an MRTS station, while the other terminal is a bus stop within the influence area. The identification of bus terminal starts from the extreme farthest point in the influence area of MRTS station subject to certain constraints. When a feeder bus route starts from a terminal, it involves the boarding of

passengers at all nodes of the path. All these passengers are to alight at the MRTS station. For the return trip, boarding is only at the MRTS station and alighting is at the nodes along the feeder path. In the routing model, the generation of feeder routes is planned based on the considerations that route lengths are within specified limits, there is no excessive meandering from the shortest path, all nodes in the influence area are served with minimum number of routes. Generation of routes is done sequentially. For each route, a set of feasible alternatives paths are generated and evaluated to select the optimal path based on the predefined criterion of 'Desire passenger-km per km'.

A heuristic algorithm is developed for determination of optimal allocation of buses on various generated feeder routes for all the stations of MRTS. The scheduling model operates for peak period and off-peak period of the day at four different levels of service. Bus type to be operated on different routes considering the various constraints is identified. As a feeder route moves from road terminal to MRTS station, the passenger flow on the links increases, as persons will be boarding at stops to reach MRTS station. Opposite will be the case, when movement is from MRTS station to road terminal. Since there may be considerable variation of the passenger flows on various links along the route, a parameter known as weighted average link flow is introduced. Bus trips to be operated on a feeder route are estimated based on maximum link flow and weighted average link flow and optimal value is assigned to the feeder route. Operational parameters are estimated. Scheduling plan for all MRTS stations and for the system is finally established.

Introduction of MRTS changes the mode choice pattern of commuters in the city. Accordingly, the MRTS would provide service on trunk routes with high passenger demand and buses would act as feeders to MRTS. Routes running parallel to MRTS corridors would become redundant and some existing bus routes may overlap with the newly generated feeder routes. Such existing routes are identified and restructured.

The Decision support system developed for feeder bus routes integrate the spatial and non-spatial database with Geographical Information System (GIS). The GIS interface

combines the maps and results together and helps to extract any relevant information. The Decision Support System uses ARCVIEW 3.1 (GIS tool) package from Environment System Research Institute (ESRI), USA. Different queries related to bus stops, MRTS stations, road and MRTS network, existing bus routes, feeder routes, overlapping routes with the MRTS corridor can be performed.

8.1.3 Computational Results for Bus Transit Network of Delhi

The methodology devised for Hub and Spokes bus transit system is effectively implemented for New Delhi, the capital city of India. The study area is divided into 192 zones and is further disaggregated to 1542 stops for computational work. The daily demand matrix of (1542 x 1542) size represents total demand of 7.67 million passengers for the year 2000.

The computational results obtained for Hub and Spokes Bus Transit Network of Delhi are:

i. The optimum number of hubs obtained for the design of bus system is 50.
ii. 181 inter-hub routes generated by considering constraints on minimum demand and length satisfies significant amount (98.81 percent) of total daily passenger demand.
iii. The maximum route length from inter-hub routes is 54.9 Km and the average route length is 21.90 Km. Maximum daily trip production of 185997 passengers is observed at Minto road terminal and is served through 45 inter-hub routes. Maximum 17 inter-hub routes terminate at Inter State Bus Terminal (ISBT).
iv. 305 secondary routes are generated for all the 50 hubs. Highest numbers of 15 secondary routes are generated within the influence area of Arun Vihar hub, while some hubs have only 1-2 routes. Six hubs, lying primarily on the outskirts of the city and with large influence area, have routes longer than 10 Km. Maximum length of 23.1 km for a secondary route is observed for Narela Mandi hub.
v. For peak period, a total fleet of 9943 buses is required for inter-hub routes at the desired level (LOS-I). The required fleet size is 7203 for LOS-IV, but it provides

a poor level of service, average and maximum bus loads being 41 and 59 respectively.

vi. During mid day period (11 A.M. to 5 P.M.), the fleet size required for the LOS-I, is only 6148 buses. The total fleet size to be commissioned will be based on the requirement for the peak period. During the peak period of 3 hours, the buses operate on an average about 51 km, while for the mid day period of 6 hours, the average operating distance is of the order of 103 km. The average passenger waiting time for the best level of service (LOS-I) is 1.4 minutes for the peak period and 2.3 minutes for mid day period. The passenger waiting time increases with the deterioration of the level of service, being 2.0 minutes for the peak period and 3.2 minutes for the mid day period at the worst level of service (LOS-IV).

vii. For peak period, a total fleet of 1554 buses for secondary routes is required at the desired level (LOS-I). For the level of service LOS-IV, the required fleet size is only 1428. During mid day period, the fleet size required for the LOS-I, is only 1460 buses. During the peak period of 3 hours, the buses operate on an average about 44 km, while for the mid day period of 6 hours, the average operating distance is of the order of 91 km. The average passenger waiting time for the best level of service (LOS-I) is 2.1 minutes for the peak period and 2.5 minutes for mid day period. The passenger waiting time increases with the deterioration of the level of service, being 2.4 minutes for the peak period and 2.8 minutes for the mid day period at the worst level of service (LOS-IV).

viii. The total fleet size required to operate a total of 486 routes for bus transit system turns out to be 11497 at LOS-I, which gets reduced to 8631 at LOS-IV. For the total bus transit system, a bus operates for 234 km per day. The average waiting time for the bus system during peak period varies from 2.4 minutes at LOS-I to 3.0 minutes at LOS-IV. The operation cost for the bus system varies from Rs. 3.91 at LOS-IV to Rs. 5.69 at LOS-I, whereas for the mid-day period, the operation cost varies from Rs. 4.60 at LOS-IV to Rs. 6.04 at LOS-I.

8.1.4 Computational Results of Feeder Bus System to Mass Rapid Transit System

The results obtained from the models of feeder bus services to MRTS can be summarized as:

i. For the mode choice model, the logit model has been considered. The estimated coefficients of parameters for travel time and travel cost are –0.001 and –0.026 respectively for both the bus transit system and MRTS. To test the sensitivity of the mode choice model with respect to different parameters and decision thresholds, the various parameters, which are of considerable importance, are studied under different scenarios. Application of the mode choice model for a scenario estimates the expected MRTS rider-ship for each O-D pair and the total MRTS demand matrix (1542x1542) is generated. Planning of feeder routes at one end or both ends of MRTS corridors with fare structure of unit rate or slab rate is considered for experimental computation. The matrices are generated for all the 108 cases of experimental design of feeder bus network. Total daily demand on MRTS for all the cases is presented. The estimated MRTS demand is out of the total daily demand of 7.67 million passengers on the existing bus transit network.

ii. Highest trips production observed are 0.19 million at the Minto road terminal stop. Highest station demand of 0.17 million is expected on the New Delhi MRTS station. Five MRTS stations have a daily station load of greater than 0.1 million passengers, eight stations have demand between 50,000 to 0.1 million, and only three stations have demand of less than 10,000 passengers. The total demand attracted from 1542 stops to the MRTS is 1.72 million, which is 22.4 percent of total demand.

iii. For demarcation of influence area of MRTS stations, Self-organizing map and Fuzzy c means clustering techniques groups all the 1542 stops in a predetermined number of clusters (Illustration given for 100 clusters). All the clusters are assigned to the nearest MRTS stations. Computational experiments have been conducted by varying the distance constraint of 10 km, 12 km and 15 Km. Heuristic approach works out the influence area for each MRTS station on a micro-analysis of each OD pair demand through MRTS, thereby assigning 1078 stops from a total of 1542 stops to the influence area of MRTS stations.

iv. Feeder routes are generated for the influence area of all MRTS stations. Computational experiments have been conducted on meandering factor for generating the feeder routes of all the MRTS stations. The values adopted for experimentation on meandering factor are 1.15, 1.25 and 1.35. Feeder routes are generated in the influence area of each MRTS station subject to a minimum distance constraint of 4 km. It is observed that as the meandering factor increases from 1.15 to 1.35, the total number of feeder routes generated for all MRTS stations decreases. For all MRTS stations, 184 feeder routes generated with a meandering factor of 1.15 decreases to 173, if meander factor is increased to 1.25 and further slightly reduced to 170 with a meandering factor of 1.35. The maximum average route length observed for station 5001 is 9.4 Km with meandering factor of 1.15, which increased to 11 km with increase in meandering factor to 1.35. As the variation in meandering factor in generating feeder routes for all MRTS stations has not much pronounced effect on the characteristics of feeder routes, therefore a meandering factor of 1.25 is assumed to be more rational for the analysis.

v. The choice of road terminal for the feeder route also depends upon the minimum specified distance constraint. To test the sensitivity of distance constraint, optimal feeder routes are generated for two different minimum distance constraint of 2 and 4 Km. A total of 259 routes are generated for all the MRTS stations, when the specified minimum distance is 2 km. The average route length for different stations ranges between 3.3 to 9.6 km, and the longest feeder route is 12.4 km long for Pitampura MRTS station. With a minimum distance constraint of 2 km, it is observed that many routes are very short. In order to avoid too much congestion of routes near the stations, when the minimum distance constraint is increased to 4 km, the number of optimal feeder routes reduces to 173 and the average route length for different stations ranges from 4.6 to 9.6 km.

vi. Scheduling of buses is made for three periods of the day namely morning peak, mid day and evening peak period. Minimum policy headway is also defined based on operational constraints. Four different levels of service (LOS I – IV) are identified for scheduling of standard and Mini buses.

vii. For peak period, a total fleet of 2396 buses is required at the highest level of service (LOS-I) and for the level of service-IV, the required fleet size is only 1879 but it provides a poor level of service, average and maximum bus loads being 32 and 67 respectively. During mid day period (11 A.M. to 5 P.M.), the fleet size required for the LOS-I, is only 1713 buses being 71.5 percent of the fleet required for the peak period. The total fleet size to be commissioned will be based on the requirement for the peak period.

viii. During the peak period of 3 hours, the buses operate on an average about 38 km, while for the mid day period of 6 hours, the average operating distance is of the order of 75 km. The average passenger waiting time for the best level of service (LOS-I) is 2.5 minutes for the peak period and 3.5 minutes for off peak period. This passenger waiting time increases with the deterioration of the level of service, being 3.2 minutes for the peak period and 4.3 minutes for the mid day period at the poor level of service (LOS-IV).

ix. The total operating cost for the bus system is determined considering an operation cost of Rs. 15 per Km. For the peak period, the operation cost per passenger is estimated to be Rs 2.24 for LOS-I and Rs 1.72 for LOS-IV. The bus operation cost for each passenger is found to be higher during the mid day period, being Rs 2.54 compared to Rs 2.24 for the peak period.

x. For restructuring of existing bus routes, a sensitivity analysis is carried out on the parameters involved in the identification of overlapping routes. For a band-width of 1 Km and minimum overlapping length of 5 Km, the number of overlapping routes reduces from 58 to 19 if the ratio of overlapping distance to total route length is increased from 0.3 to 0.5. The results indicate that the number of overlapping routes vary considerably with bandwidth. When the ratio of overlapping distance to total route length is 0.3, the number of overlapping routes are 197 for a bandwidth of 2 Km as compared to 58 overlapping routes for a bandwidth of 1 Km. Similarly when the ratio of overlapping distance to total route length is 0.5, the number of overlapping routes increases from 19 in case of 2 km bandwidth to 108 for 1 km bandwidth.

xi. Application of models for feeder bus transit system of Delhi involves the spatial and non-spatial database. Avenue programming in Arc-View 3.1 platform facilitates the conversion of output data files from optimization models to shape files and the final outcome is in the form of maps. Queries can be performed on different components of feeder bus transit system.

8.2 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn and recommendations can be made from the literature review, study methodologies and analysis of the proposed models.

- Most of the past studies deal with bus transit design problems of small to medium size networks and very limited work is available for real life transit networks for large cities. The road based public transport system in large cities of developing countries is not able to cater to the heavy demand. New rapid rail transit systems along certain corridors are being implemented in these cities. To have a convenient and efficient usage of the rapid transit system, it is desirable to provide feeder bus system so that commuters can reach MRTS stations. This involves proper integration of the bus system and the rail transit network. Very meager research work is available in the area of integration of two public transportation systems. In fact, the studies are carried out to optimize services of each public transport mode independently. The methodologies adopted in this research work for bus transit network of large cities and integration of bus transit system with mass rapid transit system through feeder routes has been successfully tested for Delhi and can be adopted for other cities also.
- The planning of bus routes based on 'Destination-oriented' approach has generally been adopted in developing countries and a large number of bus routes are evolved. These zig-zag routes overlap on certain corridors resulting in bunching on various sections of the network. Hub and spokes approach, which combines the destination-oriented approach along with direction-oriented approach, is ideally suited for such type of large networks.

- The selection of optimal hubs for the bus transit system can be facilitated through a mathematical model instead of just picking them on an intuitive basis. Clustering techniques from neural networks and fuzzy logic can be successfully applied in the optimal selection of hubs. Self-organizing map in neural networks emerges out as the better technique for grouping of stops into a number of clusters, thereby facilitating the selection of optimal hubs through the mathematical model.
- Instead of local node selection and insertion technique as resorted to in the past studies, the search has been globalized in the proposed routing model i.e. rather than expanding skeletons to routes, the major flow carrying corridors can be identified. Short-listing of alternatives through "Route utilization coefficient" and then finally selection of inter-hub routes through passenger-km per km seems to be a better method for generation of routes.
- The iterative scheduling model considers the effect of overlapping routes over a link and is recommended to calculate the optimal bus trips on a route. It depends upon the demand served along the route and the passenger flow on various links of the route. The demand served along the route can give little idea about desired bus trips, as some inter-nodal demand may be shared by more than one route. The passenger flow on the link of a route helps to determine the bus trips on a route.
- Each origin and destination stop pair in bus transit network can be connected either through secondary route within the influence area of each hub or combination of secondary and inter-hub route. This facilitates higher connectivity to all regions in the city through bus transit network.
- Hub and spokes approach reduces the number of bus routes considerably, thereby making the system simple to understand by the users and also relatively convenient from operator point of view for large networks. The approach having different series of models have been successfully applied for a large network with a fleet of more than 10,000 buses. The models consider the various operational constraints of the operators and the users. The program system is user friendly and is flexible enough to be adopted under different conditions.

- For the feeder bus transit system, Logit model of mode choice analysis is recommended to distribute the demand between the bus transit network and mass rapid transit system. The mode choice analysis is sensitive to the parameters of in vehicle travel time from origin to destination, transfer time at MRTS stations, waiting time on the bus and MRTS system, travel cost through bus and MRTS/feeder system and planning of feeder routes on one end or both ends. The operational parameters which further constraints the estimated proportion of demand are:

  i. Maximum distance from origin/destination stop to the MRTS station from where demand can be attracted
  ii. Distance traveled on MRTS corridor is greater than a certain minimum distance
  iii. Distance traveled on the MRTS corridor should be at least some proportion of the total distance between origin and destination.

  To test the sensitivity of the model with respect to different parameters and decision thresholds, the parameters that are of considerable importance in mode choice are studied under different scenario. Mode choice analysis is carried out for 108 cases to study the behaviour of the model under these scenarios. Application of mode choice model for a scenario estimates the expected MRTS rider-ship for each O-D pair and the total MRTS demand matrix is generated. Estimated MRTS demands for different scenarios indicate that the formulated mode choice model appears to give realistic results.

- Influence area for each MRTS station is demarcated for generating the feeder routes through self-organizing map, fuzzy-C-means clustering and heuristic model. Clustering techniques may be suitable to demarcate the influence area of MRTS stations at the preliminary stage. The results obtained through fuzzy-c-means clustering model do not seem to be encouraging. Heuristic approach suggested on the basis of mode choice analysis delineates the influence area for each MRTS station separately and is considered to be more rational for finally demarcating the influence area of MRTS stations.

- In the case of generation of feeder routes within influence area of MRTS stations, since the link flow goes on accumulating in the direction of MRTS station and reverse is the case in the opposite direction towards bus terminal, the criteria of desire passenger-km per km is recommended as the best representative to select the optimal path.
- The designed scheduling plan for the routes considers the effect of variation in travel demand over different periods of the day. The operating period of a route consists of five periods: early morning, morning peak, mid-day, evening peak and late evening period. The scheduling plan for each of the period can be generated in the model. The total required fleet size for the system is based on the scheduling plan for the peak period. For other off peak periods like mid-day, the activities relating to providing rest to the crew and the time associated with changing the crew can be performed.
- Standard size buses may not be operationally and economically feasible to operate on all the feeder routes. This may be due to congestion on certain narrow links or low passenger demand on some routes. The developed models are capable of designing the operational plan with Mini or small size buses on some of the feeder routes.
- The implementation of mass rapid transit system corridors will change the travel pattern on existing bus system. In order to avoid unnecessary competition between MRTS and existing bus routes running parallel to the MRTS corridors, restructuring of bus routes overlapping with MRTS corridors is suggested.
- The results obtained from models developed for feeder bus route system can be integrated with geographical information system and can be visually displayed through Arc-View platform. The Decision Support System is user friendly and queries related to various components of feeder bus route system can be done. This gives the transport planner a handy tool to have a glimpse of overall planning of the feeder bus routes for rail system in a metropolitan city.

8.3 LIMITATIONS OF RESEARCH WORK

i. Self-organizing map and Fuzzy-c-means method have been adopted for clustering operations in the design of bus transit network and for demarcating the influence area of each MRTS station in feeder bus routes planning system. Different parameters have been assumed in these two methods for the clustering purpose. Sensitivity analysis needs to be performed on these parameters before finally adopting them.

ii. For the generation of inter-hub routes in bus transit planning, the operational constraints on minimum and maximum route length are assumed. These values need to be finalized after interacting with the user agencies.

iii. For the mode choice analysis of feeder bus system, the values of travel time and travel cost along with their coefficients are only considered for calculating the utility measures of bus transit system and mass rapid transit system. Other parameters like comfort level and transfer penalty are not taken into account, since their data was not available.

iv. Coefficients of parameters for travel time and travel cost in mode choice analysis are preliminary calibrated. Further, the validation of the mode choice model could not be attempted, as the MRTS is not yet operational. Once the actual data of rider-ship is available, the adopted coefficients for different parameters may be adjusted.

8.4 RECOMMENDATIONS FOR FURTHER RESEARCH WORK

i. Only two clustering algorithms from neural networks and fuzzy logic have been considered in this research work for hub selection procedure and demarcation of influence of influence area for MRTS stations. Other clustering algorithms like Neuro- Fuzzy and Fuzzy-Art can also be explored.

ii. Mode choice analysis in feeder bus route planning system is conducted for fare structure on slab basis and unit rate. Integrated Fare structure may also be taken into consideration and analysis can be done for share of demand between bus transit network and MRTS.

iii. In this research work only the operational integration of feeder bus routes with MRTS is considered. For effective co-ordination physical and institutional integration is also required. Development of inter-modal transfer facilities at railway stations for multi-modal transit planning can be taken up for further research.

iv. An efficient integrated system demands optimization of train schedules beforehand. The developed decision support system for feeder bus routes is applied to New Delhi Metro. Co-ordination of trains timings and bus timings at MRTS stations have also to be taken into consideration, once the trains on MRTS become operational.

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APPENDIX - A

ENCLOSED CD WITH THE THESIS

Detailed data-base has been generated in this study, which may be of interest to the researchers for further studies. The enclosed CD contains the following Directories.

1. Directory for Bus transit system (HUB_BUS)
2. Directory for Feeder Bus routes to MRTS (FEED_BUS)

These directories contain the input data files and important output data files. The subdirectory 'Readme' in each directory describes the format of input data files and output files.

APPENDIX - B

DETAILS OF PATHS FOR INTER-HUB ROUTES

Origin Node	Dest-nation Node	Route Length (meters)	Intermediate nodes
192	793	47389	2769 195 2770 196 2771 2866 197 3599 198 2853 2512 2854 375 376 377 2863 355 2887 378 2886 2885 2888 1477 2889 2960 2963 963 2971 2972 1128 1127 2975 1129 1508 1117 1118 3195 1270 1359 1228 3208 1131 3207 1445 3209 3556 1326 3214 3215 3216 3218 3219 3405 1310 3221 3223 1388 3224 903 1465 3534 924 901 898 1035 1043 1044 3373 1374 1462 1538 1046 1443 3384 1357 1514 848 849 3345 1361 3342 1461 1442 3339 1540 1539 1358 3331 3604 867 3333 1530 870 866 869 1532 3459 780 788 3466 790 791 792
1212	1412	41672	1211 1213 3608 2742 2743 2744 1230 1217 1220 1219 1218 1222 2719 2720 1143 2721 3613 3614 1141 3650 1140 1139 1138 1137 1136 1135 1134 3198 1511 3197 3194 3193 3192 1385 1120 1121 1119 3189 1117 1118 3195 1115 1110 1107 1112 1106 1493 1098 2988 2992 1097 1096 1095 1094 1460 2999 3002 3007 3008 3011 1081 1080 1347 1087 1383 3012 1078 3048 1382 3016 3019 1398 3021 1426 3135 1480 3050 3051 1074 3675 1362 1436 1467 667 668 669 671 3109
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192	667	30894	2769 195 2770 196 2771 2866 197 3599 198 2853 2512 2854 375 376 377 2863 355 2887 356 22 2898 1520 2902 56 2892 2924 2899 53 2900 2901 2896 47 2895 49 1371 354 2949 318 351 1522 2951 3554 2950 5012 321 369 3677 5014 366 365 3645 5015 3028 217 1417 219 220 5016 3582 3032 3053 1413 3035 3055 1489 3036 3037 3523 3039 3524 5026 3673 1362 1436 1467

192	1181	34816	2769 195 2770 196 2771 2866 3598 3600 3601 2867 139 2876 2874 2875 200 2872 1470 2872 2877 2878 2965 1157 2968 1154 1155 2511 1153 1152 1149 1148 2765 2764 1146 1469 2720 2719 2717 1168 1170 1171 2727 1175 1176 1180 2722
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1181	1508	30566	2722 1180 1176 1175 2727 1171 1170 1168 2717 2719 2720 1143 2721 1144 1142 2728 1224 1223 1225 1226 3632 3631 3629 3628 3626 3411 3410 3412 3618 3407 1275 1279 1285 3406 3213 1289 1290 1291 1334 3660 3204 3205 1305 1343 1342 3188 3187 1346 3190 3189 1117
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887	1460	24862	3439 3438 888 3444 703 702 3443 701 3346 699 1504 3347 1459 3342 3344 698 953 3343 1423 697 696 3260 624 854 852 1541 3263 851 690 3119 644 3129 683 1479 681 3109 671 669 668 667 1467 1436 1362 3675 1074 3051 3050 1480 3135 1424 842 3049 759 758 717 3024 746 3025 732 3160 1395 718 724 1389 1499 3007 3002 2999
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627	1413	29119	3316 3311 606 608 3301 3302 3304 3289 3290 614 3292 583 1524 573 574 3498 575 577 588 576 579 545 551 3091 495 494 3087 3088 3089 478 480 3505 3504 438 3500 436 398 1471 398 436 511 512 460 3506 453 3647 1501 454 451 455 3065 458 3064 3063 459 3061 3059 2506 3058 2507 1490 3055 3035
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1016	1412	22468	3485 3484 974 973 972 3430 971 3482 3483 875 3561 876 3562 887 3439 3438 888 3444 703 702 3443 701 3346 699 1504 3347 1459 3342 3344 698 953 3343 1423 697 696 3260 624 854 852 1541 3263 851 690 3119 644 3129 683 1479 681 3109
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333	1413	18218	2628 273 2627 2626 2629 2630 2631 112 113 114 2798 2797 2809 2801 2800 4 2832 1425 2830 2 1 1351 1350 2829 1349 379 381 300 1356 2828 1484 386 2931 388 2932 2935 2934 183 2945 3580 3672 222 221 3032 3053
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559	887	23680	592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 3122 1496 3123 3124 3125 3126 1494 1420 1474 3171 733 5029 725 731 3138 5030 3173 1438 3238 3531 3239 3241 740 3533 3236 741 3243 742 3248 743 3351 1505 3383 1409 3385 3591 775 1431 3384 880 1049 3441 3442 960 961 964 3434 3435 3594 3437 3438 3439
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887	1077	18845	3439 3438 888 3444 703 702 3443 701 3346 699 1504 3347 1459 3342 3344 698 953 3343 1423 697 696 3260 3259 3256 3254 933 3253 3528 3147 3144 3139 722 721 3125 3126 3127 3128 3120 1072 3132 858 850 857 3049 842 1424 3135 1426 3021 1398 3019
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1438	1471	17750	3238 3530 3139 3143 3140 3264 3267 685 3265 686 687 681 3109 1412 1410 3107 542 541 1441 552 543 1503 544 3100 547 556 550 546 3098 514 500 3077 513 3076 3080 510 508 509 524 3069 486 506 5021 453 3506 460 512 511 436 398
1438	1520	22187	3173 1406 3137 3136 3152 1038 3159 3158 835 3549 1535 3548 2508 859 3164 3160 1395 718 724 1389 1499 3007 3002 2999 1460 1094 1095 1096 1097 2992 2988 1098 1493 1106 1112 1107 1110 1115 3195 1118 1117 1508 1129 2975 1127 1128 2972 2971 963 2963 2960 2889 1477 2888 3543 3544
1443	1484	17222	3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 938 3247 3244 3245 3250 926 3145 3139 722 721 3125 3126 3127 3128 3120 3121 3122 667 1467 1436 1362 3675 1069 3052 3043 3044 3029 1068 3030 3031 218 1417 347 1519 1451 179 2946 3655 2935 2932 388 2931 386
1383	1471	20737	3012 1078 3048 1382 3016 3019 1398 3021 1426 3135 1480 3050 3051 1074 3675 1362 1436 1467 667 668 669 671 3109 1412 1410 3107 542 541 1441 552 543 1503 544 3100 547 556 550 546 3098 514 500 3077 513 3076 3080 510 508 509 524 3069 486 506 5021 453 3506 460 512 511 436 398
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1363	1533	17279	1364 3518 3516 538 3061 3059 2506 657 3056 1419 3523 3039 3524 5026 3673 1362 1436 1467 667 3122 1496 3123 3124 3125 721 722 3139 3145 926 3250 3245 3244 3247 938 3248 743
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1443	1506	15223	3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 938 3247 3244 3245 3250 926 3145 3139 722 721 3125 3126 3127 3128 3120 3121 3122 667 1467 1436 1362 3675 1069 3052 3043 3044 3029 1068 3030 3031 218 1417 347 361 1507 1375 345 2927
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32	1413	17244	2962 2953 2952 41 1156 42 666 43 1475 342 1371 46 2906 58 2907 5009 59 60 2838 2948 1352 1523 64 61 64 2909 2829 1349 337 289 336 395 1483 57 343 2927 345 1375 1507 361 347 1417 219 220 5016 3582 3032 3053
559	1363	14542	592 3103 3102 593 3101 2503 3099 3098 514 500 3077 513 3076 3080 510 508 509 524 3069 486 506 5021 453 3506 460 3506 453 447 1365 433 448 3503 446 3512 445 3513 3510 404 409 1363
544	1506	12925	3100 535 534 1437 529 531 3093 530 3094 537 3499 519 3067 3521 3056 657 2506 3058 2507 1490 3055 3035 1413 3053 3032 3582 5016 220 219 1417 347 361 1507 1375 345 2927
32	1438	16755	2962 33 3564 3563 2986 1104 1103 1102 2984 2985 1101 1098 1493 1106 1112 1107 1112 1106 1493 1098 2988 2992 1097 1096 1095 1094 1460 2999 3002 3007 1499 1389 724 718 1395 3160 3164 859 2508 3548 1535 3549 835 3158 3159 1038 3152 3136 3137 1406 3173
1285	1469	13952	1279 1275 3407 3618 3412 3410 3411 3626 3628 3629 3631 3632 1226 1225 1223 1224 2728 1142 1144 2721 1143 2720
1506	1533	13880	2927 345 1375 1507 361 347 1417 217 3028 3676 3047 1061 1062 3046 1063 1083 1082 1077 3019 1398 3021 1426 3135 1424 842 3049 857 850 1404 3555 932 3157 3155 727 1473 3137 1406 3173 1438 3238 3531 3239 3241 740 3533 3236 741 3243 742 3248 743
292	1413	14149	291 1369 2807 2806 2509 249 2805 247 2827 228 241 2826 240 239 244 243 2937 1484 386 2931 388 389 180 1452 457 390 344 391 2927 1506 2927 345 1375 1507 361 347 1417 219 220 5016 3582 3032 3053
32	1484	17847	2962 33 3564 3563 2986 1104 1103 1102 2984 2985 1101 1098 1493 1106 1112 1107 1112 1106 1493 1098 2988 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315 5012 321 369 5013 532 368 392 2926 1506 2927 391 344 390 457 1452 180 389 388 2931 386
559	1471	12363	592 3103 3102 593 3101 2503 3099 544 3100 547 556 550 546 3098 514 500 3077 513 3076 3080 510 508 509 524 3069 486 506 5021 453 3506 460 512 511 436 398
559	1077	12129	592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 1467 1436 1362 3675 1074 3051 3050 1480 3135 1426 3021 1398 3019
559	1504	14218	592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 681 1479 683 3129 644 3119 690 851 3263 1541 852 854 624 3260 696 697 1423 3343 953 698 3344 3342 1459 3347
545	1438	13676	578 3096 3077 500 514 3098 546 550 556 547 3100 544 1503 543 552 1441 541 542 3107 1410 1412 3109 671 669 668 667 3122 1496 3123 3124 3125 3126 1494 1420 1474 3171 733 5029 725 731 3138 5030 3173
61	1508	13210	64 1523 1352 2948 2838 60 59 5009 2907 58 2906 46 1371 342 1476 3001 2998 360 3550 1093 2999 1460 1094 1095 1096 1097 2992 2988 1098 1493 1106 1112 1107 1110 1115 3195 1118 1117
841	1412	12710	3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775

			3591 3385 1409 3383 1505 3351 743 1533 3389 3269 947 943 942 3249 3257 3256 3262 693 3263 851 690 3119 644 3129 683 1479 681 3109
1016	1443	15785	3485 3484 974 973 972 3430 971 3482 3483 875 3561 876 3562 887 3439 3438 3437 3594 3435 3434 964 961 960 3442 3441 1049 880 3384
61	1363	11932	64 2909 2829 1349 379 381 300 1356 2828 1484 1405 2939 2938 232 233 234 235 2825 393 311 308 310 407 408 405 1364
32	1285	12372	2997 2961 3566 3565 2963 963 2971 2972 1128 1127 2975 1129 1508 1117 3189 3190 1346 3187 3188 1342 1343 1305 3205 3204 3660 1334 1291 1290 1289 3213 3406
559	1533	14727	592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 3122 1496 3123 3124 3125 721 722 3139 3145 926 3250 3245 3244 3247 938 3248 743
1025	1412	15320	3223 1388 3224 915 905 904 3168 3158 900 899 759 3022 3021 1398 3019 1077 3019 1398 3021 1426 3135 1480 3050 3051 1074 3675 1362 1436 1467 667 668 669 671 3109
451	1438	14641	50 451 454 1501 3647 5020 504 522 506 486 3069 524 509 508 510 3080 3076 513 3077 500 514 3098 546 550 556 547 3100 544 1503 543 552 1441 541 542 3107 1410 1412 3109 681 687 686 3265 685 3267 3264 3140 3143 3139 3530 3238
451	1383	12970	455 3065 458 3064 3063 459 3061 3059 2506 657 3056 1419 3523 3039 3524 5026 3673 1362 1436 1467 667 1467 1436 1362 3675 1074 3051 3050 1480 3135 1426 3021 1398 3019 3016 1382 3048 1078 3012
61	333	11061	64 2909 2829 1350 1351 1 2 2830 1425 2832 4 2800 2801 2809 2797 2798 114 113 112 2631 2630 2629 2626 2627 273 2628 333
6	1383	15377	2840 2841 1449 2842 260 2843 2917 20 2916 19 2891 21 2898 1520 2902 56 2892 2924 2899 53 2900 2901 2896 47 2895 49 1371 354 2949 318 351 1522 2951 319 317 316 1088 3009 3010 1488 1086 3014 3012
898	1383	15283	1035 1043 1044 3373 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173 1406 3137 1473 727 3155 3157 932 3555 1404 850 857 3049 842 1424 3135 1426 3021 1398 3019 3016 1382 3048 1078 3012
544	1533	14259	1503 543 552 1441 541 542 3107 1410 1412 3109 681 1479 683 3129 644 3119 690 851 3263 1541 852 854 624 3260 696 697 1423 3343 953 3343 3536 951 3388 3669 3389
32	374	12162	2997 2961 3566 3565 3567 2889 1477 2888 3543 3544 1520 2898 22 356 2887 355 2863 377 376 375 2854 2512 2853 198 3599 197
32	1383	12141	2962 33 27 28 35 36 2995 3540 2998 360 3550 1093 2999 3002 3007 1499 1389 724 718 1395 3160 732 3025 746 3024 717 758 3020 3019 1398 3019 3016 1382 3048 1078 3012
451	559	9254	454 1501 3647 5020 504 522 506 486 3069 524 509 508 510 3080 3076 513 3077 500 514 3098 546 550 556 547 3100 544 3099 2503 3101 593 3102 3103 592 559
61	724	11349	64 1523 1352 277 2908 2910 278 287 2925 3578 285 284 2926 392 368 532 5013 370 3026 3010 1488 1086 3014 3012 1383 3012 3013 1080 1081 3011 728 724
1025	1107	9018	3391 1309 3392 1402 3216 3215 3214 1326 3556 3209 1445 3207 3184 1408 1076 3180 1114 1113 1111 2989
1025	1508	10884	3391 1309 3392 1402 3216 3215 3214 1326 3556 3209 1445 3207 3184 1408 1076 3180 1114 1113 1111 2989 1107 1110 1115 3195 1118 1117
6	32	9589	2840 2841 1449 2842 260 2843 2917 20 2916 19 2891 21 2898 1520 3544 3543 2888 1477 2889 3567 3565 3566 2961 2997
724	1484	10505	718 1395 3160 732 3025 746 3024 717 758 3020 3019 1398 3019 1077 1082 1062 1061 1384 3028 217 1417 347 1519 1451 179 2946 3655 2935 2932 388 2931 386
6	1484	12009	334 2839 3668 2835 2836 2837 2838 2948 1352 277 2908 2910 278 287 2925 3578 285 284 2926 1506 2927 391 344 390 457 1452 180 389 388 2931 386
1025	1285	8589	719 3393 1315 1318 3402 3396 3399 1313 3400 1297 1296 3409 1288
841	953	10648	3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 1533 3389 3669 3388 951 3536 3343
841	1025	7834	3386 1041 3375 1042 3380 3382 1537 3586 1374 3373 1044 1043 1035 898 901 924 3534 1465 903 3224 1388 3223
724	1506	8224	718 1395 3160 732 3025 746 3024 717 758 3020 3019 1077 1082 1062 1061 1384 3028 217 1417 347 361 1507 1375 345 2927
841	1504	7682	3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1357 1514 848 849 3345 1361 3342 1459 3347
1504	1533	5656	3347 1459 3342 3344 698 953 3343 3536 951 3388 3669 3389
545	559	6709	578 3096 3077 500 514 3098 546 550 556 547 3100 544 3099 2503 3101 593 3102 3103 592
61	1506	6975	64 2909 2829 1349 379 381 300 1356 2828 1484 386 2931 388 389 180 1452 457 390 344 391 2927
6	61	4791	334 2839 3668 2835 2836 2837 62
752	1504	3797	753 1466 754 751 750 1396 3341 749 3347
1077	1383	1519	3019 3016 1382 3048 1078 3012

APPENDIX – C

DETAILS OF PATH FOR SECONDARY ROUTES

Origin stop	Hub stop	Length (meters)	Intermediate stops
78	6	5144	2781 269 2787 2786 267 2846 266 2861 2845 2839 334
3	6	4687	2832 4 2800 72 1368 3577 2791 2839 334
5	6	4860	2798 2797 2809 2801 2800 72 1368 3577 2791 2839 334
268	6	5692	2788 5004 2849 263 5005 259 258 262 264 265 2860 335 2840
270	6	4489	2789 2785 2786 267 2846 266 2861 2845 2839 334
69	6	3458	70 71 3577 2791 2839 334
341	32	3464	2985 2984 1102 1103 1104 2986 3563 3564 39 2997
1108	32	2727	1105 2986 3563 3564 39 2997
34	32	2130	2995 36 35 28 27 33 2962
203	61	4769	3578 2925 286 2911 280 279 2910 2908 277 1352 1523 64
15	61	3516	16 2897 14 2907 5009 59 60 2838 2948 1352 1523 64
68	61	3473	3657 2831 67 3576 66 65 63 62
282	61	3460	281 2912 2911 280 279 2910 2908 277 1352 1523 64
349	61	5067	348 325 3646 353 323 2913 2912 2911 280 279 2910 2908 277 1352 1523 64
338	61	3067	288 287 278 2910 2908 277 1352 1523 64
12	61	4177	2921 2920 11 2897 14 2907 5009 59 60 2838 2948 1352 1523 64
155	96	22885	2551 2550 2549 150 2542 2543 2546 2545 26 2547 2570 2675 276 327 328 329 330 331 332 2538 2532 2530 2525 2514 95 3615
156	96	16607	3 24 156 158 2541 2540 157 2544 2545 26 2547 2570 106 105 2538 2532 92 2531 2533 2529 2524 2525 2514 95 3615
159	96	8496	2528 160 2513 161 163 164 1472 97
162	96	7219	2517 161 163 164 1472 97
91	96	6243	93 2533 2529 2524 2525 2514 95 3615
1448	96	5582	3493 100 2527 99 2526 98 2523 2522 2521 2514 95 3615
166	96	3046	165 1472 97
215	192	8714	2768 211 119 210 120 122 123 124 1429
136	192	7252	3597 135 194 3609 1429
121	192	6878	2694 2695 2696 2693 2691 2689 2690
191	192	6601	2676 2677
134	192	6569	135 194 3609 1429
137	192	6421	194 3609 1429
133	192	5217	2770 195 2769
297	292	6451	298 2811 2812 2813 2807 1369 291
248	292	4770	249 2509 2806 2807 1369 291
152	333	18805	154 2558 2549 150 2542 2543 2546 2545 26 2547 2570 2675 276 326 274 2656 2654 275 2653
153	333	18036	2573 2552 2553 148 2550 2549 150 2542 2543 2546 2545 26 2547 2570 2675 276 326 274 2656 2654 275 2653
151	333	17354	2558 2549 150 2542 2543 2546 2545 26 2547 2570 2675 276 326 274 2656 2654 275 2653
149	333	11029	2566 118 2567 2568 2546 2545 26 2547 107 1353 108 2583 109 2587 2586 110 2624 2626 2627 273 2628
116	333	11421	2564 2565 2595 117 2567 2568 2546 2545 26 2547 107 1353 108 2583 109 2587 2586 110 2624 2626 2627 273 2628
158	333	8986	2541 2540 157 2544 2545 26 2547 2570 2516 2584 2628
115	333	7680	2604 2598 2594 2593 2592 2590 2588 2587 2586 110 2624 2626 2627 273 2628
296	333	7258	2612 2611 2610 2636 2635 2634 2633 113 112 2631 2630 2629 2626 2627 273 2628

1521	333	6265	2637 2589 2588 2587 2586 110 2624 2626 2627 273 2628
111	333	2332	2625 2624 2626 2627 273 2628
87	374	8012	3617 85 2668 2667 84 2773
79	374	7609	81 83 82 2774 3595 2664 84 2773
86	374	8593	2674 2672 2673 85 2668 2667 84 2773
80	374	8767	2779 79 81 83 82 2774 3595 2664 84 2773
1418	451	3901	3073 507 1434 3069 486 506 522 504 5020 3647 1501 454
429	451	3514	431 452 3506 453 3647 1501 454
435	451	4751	434 3503 448 3515 432 456 450 3065 455
430	451	4880	434 3503 448 3515 432 456 450 3065 455
499	460	6466	3078 505 3079 3075 487 3080 548 3072 1440 523 507 1434 3069 486 506 5021 453 3506
490	460	6231	3079 3075 487 3080 548 3072 1440 523 507 1434 3069 486 506 5021 453 3506
496	460	5359	3090 3091 495 494 473 472 471 463 480 3505 462 461 1526 1502
489	460	6694	490 3079 3075 487 3080 548 3072 1440 523 507 1434 3069 486 506 5021 453 3506
498	460	5939	3083 3082 490 489 488 3092 3081 595 482 483 1525 3069 486 506 5021 453 3506
501	460	5475	3075 487 3080 548 3072 1440 523 507 1434 3069 486 506 5021 453 3506
485	460	4487	474 3081 595 482 483 1525 3069 486 506 5021 453 3506
484	460	5255	485 474 3081 595 482 483 1525 3069 486 506 5021 453 3506
497	460	5153	3087 494 473 472 471 463 480 3505 462 461 1526 1502
1518	460	4714	485 474 3081 595 482 483 1525 3069 486 506 5021 453 3506
533	460	3904	3087 3088 3089 478 480 3505 462 461 1526 1502
492	460	4868	1518 485 474 3081 595 482 483 1525 3069 486 506 5021 453 3506
525	460	3222	1434 3069 486 506 5021 453 3506
481	460	3222	3088 3089 478 480 3505 462 461 1526 1502
1399	544	4105	518 3067 519 3499 520 530 3093 531 529 1437 534 535 3100
528	544	2771	520 530 3093 531 529 1437 534 535 3100
1400	544	3996	3094 530 3093 531 529 3070 549 3074 1527 3098 546 550 556 547 3100
526	544	2611	3071 3070 529 1437 534 535 3100
536	544	2507	3094 530 3093 531 529 1437 534 535 3100
527	544	3377	3071 3070 549 3074 1527 3098 546 550 556 547 3100
539	544	2686	3106 540 590 541 1441 552 543 1503
572	545	4986	3293 573 574 3498 575 577 3097 1215 3096 578
503	545	2613	502 3077 3096 578
566	559	4481	567 3275 3276 568 449 564 563 3278 587 1510 3273 3272 560
565	559	3717	568 449 564 563 3278 587 1510 3273 3272 560
571	559	2606	1455 3274 591 3103 592
561	559	2465	569 570 592
557	559	2407	1454 3102 3103 592
586	559	2290	3278 587 1510 3273 3272 560
580	627	6579	581 582 583 3292 614 3290 3289 3304 3302 3301 608 606 3311 3316
612	627	4705	3298 3297 622 3314 3313 606 3311 3316
613	627	4647	616 610 3295 3653 3314 3313 606 3311 3316
1516	627	4638	3285 614 3290 3289 3304 3302 3301 608 .606 3311 3316
619	627	4428	3294 620 3296 3653 3314 3313 606 3311 3316
611	627	4123	3294 620 3296 3653 3314 3313 606 3311 3316
632	627	4095	3322 3320 3319 630 626 3495 3310
601	627	4058	3281 603 3287 618 3300 605 3299 628 1517 3494 3495 3310
609	627	3909	3291 3290 3289 3304 3302 3301 608 606 3311 3316
615	627	3360	3289 3304 3302 3301 608 606 3311 3316
631	627	3226	3320 3319 630 626 3495 3310
621	627	3208	3298 3297 622 3314 3313 606 3311 3316
604	627	2992	3300 605 3299 628 1517 3494 3495 3310
607	627	2658	3302 3301 608 606 3311 3316
617	627	2065	3318 3315 3316
930	667	1742	3128 3120 3121 3122
661	667	2477	5026 3673 1362 1436 1467
1447	667	1883	662 3148 663 3527 1457 665 3149
664	667	2428	1390 1447 662 3148 663 3527 1457 665 3149
1071	667	940	3121 3122
1500	667	1643	931 3127 3128 3120 3121 3122
653	724	4706	638 637 636 3175 635 3174 493 477 584 633 3007 1499 1389
641	724	5058	653 638 637 636 3175 635 3174 493 477 584 633 3007 1499 1389
646	724	5340	641 653 638 637 636 3175 635 3174 493 477 584 633 3007 1499 1389
658	724	3683	3166 689 3162 3160 1395 718
897	724	2735	3169 2508 859 3164 3160 1395 718

659	724	2307	3163 3162 3160 1395 718
807	752	5655	708 709 3478 705 3477 711 704 3444 703 702 3443 762 768 3447 1466 753
871	752	7259	3472 3471 1512 3450 767 3449 765 747 3445 763 762 768 3447 1466 753
706	752	5634	708 709 3478 705 3477 711 704 3444 703 702 3443 762 768 3447 1466 753
707	752	5876	706 708 709 3478 705 3477 711 704 3444 703 702 3443 762 768 3447 1466 753
710	752	6075	707 706 708 709 3478 705 3477 711 704 3444 703 702 3443 762 768 3447 1466 753
865	752	3725	3323 864 863 3326 868 3332 3355 785 784 3453
766	752	4304	3449 765 747 3445 763 762 768 3447 1466 753
894	752	3976	893 1529 3462 891 3662 1464 1433 1432 3448 755 1466 753
764	752	4241	3458 765 747 3445 763 762 768 3447 1466 753
776	752	2873	787 786 3332 3355 785 784 3453
1401	752	2745	890 889 891 3662 1464 1433 783
781	752	2609	3465 3456 3455 3454 3453
892	752	3578	890 1401 757 3456 3455 3454 3453
748	752	2221	3446 768 3447 1466 753
779	793	7696	3463 778 3664 3460 3457 3468 3470 799 3467
782	793	7228	3464 3664 3460 3457 3468 3470 799 3467
803	793	4168	3468 3470 799 3467
789	793	4127	3466 790 791 792
797	793	3166	796 794 795 3467
798	793	2037	799 3467
982	841	9413	3423 3422 820 3588 3379 3378 3587 1029 811 815 3367 847 1032 845 819 846 3376 1458 3426 3386
981	841	9254	3421 980 3422 820 3588 3379 3378 3587 1029 811 815 3367 847 1032 845 819 846 3376 1458 3426 3386
978	841	8192	977 3421 980 3422 820 3588 3377 818 846 3376 1040 827 3374 1495 3381 3382 3380 1042 3375 1041 3386
979	841	8419	978 977 3421 980 3422 820 3588 3377 818 846 3376 1040 827 3374 1495 3381 3382 3380 1042 3375 1041 3386
976	841	6425	1534 822 3425 3490 828 3387 843 1458 3426 3386
812	841	3687	814 3587 3378 813 819 846 3376 1458 3426 3386
817	841	3534	3379 3378 813 819 846 3376 1458 3426 3386
824	841	2893	3424 825 3425 3490 829 821 3589
826	841	2580	3424 825 3425 3490 829 821 3589
844	841	2007	844 3387 828 3426 3386
987	887	11069	3485 3484 974 973 972 3430 969 3593 970 3431 968 834 967 837 836 3433 3434 3435 3594 3437 3438 3439
997	887	10807	1377 3484 974 973 972 3430 969 3593 970 3431 968 834 967 837 836 3433 3434 3435 3594 3437 3438 3439
975	887	10779	974 973 972 3430 969 3593 970 3431 968 834 967 837 836 3433 3434 3435 3594 3437 3438 3439
832	887	5869	3428 833 967 834 968 3431 970 3593 969 3430 971 3482 3483 875 3561 876 3562
999	887	6018	998 879 3481 3482 3483 885 877 886 3439
1463	887	5576	3429 3430 971 3482 3483 885 877 886 3439
716	887	3984	3474 714 3475 3476 873 3480 3562
1513	887	3732	3474 714 3475 3476 873 3480 3562
966	887	3361	966 1531 878 3440 877 886 3439
712 –	887	2870	3477 705 3478 1515 3479 3562
908	898	5292	3225 909 907 3224 903 1465 3534 809 3372 1030 808 3371
911	898	5528	908 3225 909 907 3224 903 1465 3534 809 3372 1030 808 3371
1048	898	4948	3225 909 907 3224 903 1465 3534 809 3372 1030 808 3371
935	898	4950	3225 909 907 3224 903 1465 3534 809 3372 1030 808 3371
1054	898	2462	1045 1374 3373 1044 1043 1035
805	898	2137	806 3372 1030 808 3371
1495	898	2502	3374 1036 3365 1034 3370 3371
773	953	4243	1421 3336 3338 772 771 1423 3343
647	953	3632	1358 1539 1540 3339 1442 3661 3344 698
695	953	3492	853 3261 3260 696 697 1423 3343
856	953	4519	1421 773 3535 3337 771 1423 3343
769	953	2991	770 777 3661 3344 698
1394	953	2809	3350 3349 952 3536 3343
855	953	2647	3261 3260 696 697 1423 3343
1422	953	2531	3350 3349 952 3536 3343
896	953	2332	3349 952 3536 3343
1249	983	7483	1250 3558 1255 3559 3416 3417
1252	983	6536	3558 1255 3559 3416 3417
1253	983	5988	1254 1256 3418 1021 3416 3417

1302	983	5906	1303 1026 3395 1304 3420 985 3419 3487
1277	983	5800	3415 1416 1019 1020 1299 3419 3487
1278	983	5475	3415 1416 1019 1020 1299 3419 3487
1257	983	4658	1428 3418 1021 3416 3417
1024	983	4287	1024 3491 2501
1023	983	4108	1022 3417
1013	1016	15652	1014 1012 1011 1010 1009 1008 1007 1006 1005 1004 1003 1002 1001 1000 997 1377 3484 3485
996	1016	12563	995 994 993 992 991 990 3492 989 988 987 3485
1018	1016	2212	1017 1015
1323	1025	4824	1327 3556 1326 3214 3215 3216 1402 3392 1309 3391
1317	1025	4422	3398 1314 3397 3396 3402 1318 1315 3393 719
1325	1025	4229	1324 3214 3215 3216 1402 3392 1309 3391
1303	1025	4124	1026 3395 816 1027 3394 1307 1316 1028 719
1328	1025	3851	3217 1322 3216 1402 3392 1309 3391
1319	1025	3756	3397 3396 3402 1318 1315 3393 719
1320	1025	3191	3557 3220 1402 3392 1309 3391
1312	1025	3032	3220 1402 3392 1309 3391
367	1077	5202	364 363 3027 365 3645 5015 3028 3030 1068 3029 1064 3676 1384 1061 1062 1082
1370	1077	2760	1065 3047 1061 1062 3046 1063 1083 1082
739	1077	2145	3018 3017 1348 3020 3019
475	1107	6030	380 444 3178 3539 322 3177 1060 2994 339 1099 3179 2991 1112
299	1107	5455	444 3178 3539 322 3177 1060 2994 339 1099 3179 2991 1112
307	1107	3868	307 3177 322 3539 3176 339 1099 3179 2991 1112
1073	1107	3417	1070 3183 1075 3182 3180 1114 1113 1111 2989
18	1107	3954	44 3539 3176 339 1492 2992 2988 1098 1493 1106 1112
1244	1142	9063	1243 2510 2730 2729 1224 2728
1248	1142	7452	2751 1271 1242 2510 2730 2729 1224 2728
1232	1142	7326	1216 1231 2753 1229 2729 1224 2728
1240	1142	5610	1246 1227 1226 1225 1223 1224 2728
1241	1142	5276	1247 2510 2730 2729 1224 2728
1260	1142	5173	1261 1225 1223 1224 2728
1221	1142	2217	2728
1174	1181	8454	2726 1173 2750 1192 1191 1175 1176 1180 2722
1169	1181	7260	2718 1175 1176 1180 2722
1380	1181	6901	2738 2737 2736 1184 1185 1187
1172	1181	6726	2727 1175 1176 1180 2722
1190	1181	5564	2735 2736 1184 1185 1187
1195	1181	5219	1196 1194 2725 2723 1180 2722
1193	1181	5218	1194 2725 2723 1180 2722
1189	1181	5166	1188 2732 1186 1187
1179	1181	3996	2749 1177 2722
1178	1181	3206	2749 1177 2722
1183	1181	3024	2724 2723 1180 2722
1245	1212	8283	1244 1214 1239 2755
1207	1212	7265	1206 2756 2757 1205 1202 2741 1200 1199 1210
1386	1212	6093	1209 1208 2757 1205 1202 2741 1200 1199 1210
1234	1212	5952	1235 2745 2758 2743 2742 3608 1213 1211
1233	1212	5722	2760 2748 1238 1237 1236 2755
1204	1212	5304	1203 1202 2741 1200 1199 1210
1197	1212	4686	1198 1201 2741 1200 1199 1210
1251	1285	19700	2510 2730 2729 1224 1223 1225 1226 3632 3631 3629 3628 3626 3411 3410 3412 3618 3407 1275 1279
1259	1285	8886	1138 3200 3201 3623 3624 1272 3411 3410 3412 3618 3407 1275 1279
1262	1285	6279	3622 3199 3200 3201 1282 1283 3202 1281 1280 3203 1284 3213 3406
1269	1285	4786	3639 1268 3640 3630 3628 3626 3411 3410 3412 3618 3407 1275 1279
1273	1285	6534	3625 1272 3624 1264 3414 3412 3618 3407 1275 1279
1267	1285	5241	3631 1273 3625 1272 3411 3410 3412 3618 3407 1275 1279
1274	1285	2866	3633 3635 3407 1275 1279
1263	1285	2523	3410 3412 3618 3407 1275 1279
1276	1285	2343	3619 3408 1288
423	1363	8474	420 2817 419 411 2821 418 415 417 416 2818 414 2819
412	1363	8238	2815 2822 410 2821 411 426 3519 3509 404 409
421	1363	6403	2817 419 411 2821 418 415 417 416 2818 414 2819
424	1363	6253	425 2820 422 426 411 2821 418 415 417 416 2818 414 2819
427	1363	4296	2820 422 426 3519 3520 413 2819

1439	1363	3607	3654 3508 403 3511 3510 404 409
1486	1371	2092	50 52 2894 2895 49
283	1383	4908	284 2926 392 368 532 3677 370 3026 3010 1488 1086 3014 3012
373	1383	3219	1381 372 371 3026 3010 1488 1086 3014 3012
1487	1383	2895	3026 3010 1488 1086 3014 3012
965	1398	2461	3151 962 857 3049 842 1424 3135 1426 3021
694	1412	3079	3262 693 3263 851 690 3119 644 3129 683 1479 681 3109
650	1412	3007	3268 649 652 3110 3107 1410
679	1412	2318	851 690 3119 644 3129 683 1479 681 3109
654	1412	2311	1411 3110 3107 1410
655	1412	3009	3108 654 1411 3110 3107 1410
688	1412	2798	3141 677 3140 3264 3267 685 3265 686 687 681 3109
1478	1412	2254	651 690 3119 644 3129 683 1479 681 3109
516	1413	6149	3060 3062 3059 2506 3058 2507 1490 3055 1435 5025 3656 1397 3034 3033 185 1453
656	1413	5278	3057 3525 1419 3522 3037 3036 1489 3055 1435 5025 3656 1397 3034 3033 185 1453
1366	1413	2323	3036 1489 3055 3035
910	1438	3272	3226 3227 918 917 3234 3235 3532 1376 3173
912	1438	2918	1047 913 3136 3137 1406 3173
1037	1438	2183	3159 1038 3152 3136 3137 1406 3173
902	1438	2150	3153 735 3157 3155 727 1473 3137 1406 3173
584	1460	2672	633 3007 3002 2999
214	1469	10690	2698 2699 2700 2701 1509 1167 1166 2713 1165 2714 1164 2715 1159 1145 3612
212	1469	10236	2702 2700 2701 1509 1167 1166 2713 1165 2714 1164 2715 1159 1145 3612
213	1469	9722	2701 1509 1167 1166 2713 1165 2714 1164 2715 1159 1145 3612
1162	1469	6949	2706 1161 2707 2766 1160 2763 1146
1151	1469	6721	1150 1149 1148 2765 2764 1146
1266	1469	4862	1148 2765 2764 1146
1147	1469	3880	2763 1146
1163	1469	4603	2716 1159 1145 3612
1542	1470	9545	1155 2511 2967 206 207 205 208 202 201 200 2872
193	1470	8640	2511 2967 206 207 205 208 202 201 200 2872
358	1470	3942	138 2874 2875 142 2873 2872
143	1470	2864	2882 2505 2873 2872
23	1470	2378	2883 2882 2505 2873 2872
141	1470	2382	142 2873 2872
472	1471	6560	471 463 480 3505 3504 634 467 3502 3507 469 442 468 3501 394 440
479	1471	5045	481 3088 3089 478 480 3505 3504 634 467 3502 441 468 3501 394 440
476	1471	5930	3089 478 480 3505 3504 634 467 3502 3507 469 442 468 3501 394 440
462	1471	3849	3505 3504 438 466 443 3501 394 440
401	1471	3086	428 429 511 436 398
461	1471	3714	1526 3500 438 466 443 3501 394 440
464	1471	2967	470 3502 441 468 3501 394 440
465	1471	3433	465 464 470 3502 441 468 3501 394 440
397	1471	2664	399 439 396 437 440
88	1482	9556	1367 167 168 169 177 178 2685 2681 174
190	1482	9178	2678 189 188 178 2685 2681 174
129	1482	6164	129 2684 2683 2682 176 175 2681 174
170	1482	5375	171 1355 172 173 174
242	1484	7184	2824 309 308 310 2940 312 229 1450 2942 3658 230 2933 2934 2935 2932 388 2931 386
305	1484	4264	306 2941 304 182 2933 2932 388 2931 386
236	1484	2515	2825 235 234 233 232 2938 2939 1405
237	1484	2277	3674 234 233 232 2938 2939 1405
837	1504	5243	836 3433 3434 3435 3436 761 760 3443 701 3346 699
1456	1504	4410	3594 3435 3434 964 961 960 3442 957 3354 958 959 700 3346 699
955	1504	2524	956 954 3345 1361 3342 1459 3347
223	1506	3227	3672 3580 1451 346 1375 345 2927
184	1506	2823	3580 1451 346 1375 345 2927
1265	1508	9391	1292 1293 1294 3212 3210 3211 1330 1331 1332 1333 3660 3204 1336 1340 1338 1337 1481 3197 3194 3193 3192 1385 1120 1121 1119 3189 1117
1133	1508	6721	1132 3198 1511 3197 1481 1337 1338 1340 1336 1335 1344 3188 3187 1346 3190 3189 1117
1329	1508	5639	3210 3211 1330 1331 1332 1333 3660 3204 3205 1305 1343 1342 3188 3187 1346 3190 3189 1117
1446	1508	4576	3207 3184 1408 1079 1258 1359 1270 3195 1118 1117
1123	1508	3649	3569 1125 3568 1124 1126 2973 2974 2975 1129

1301	1508	3358	1298 3206 1300 3185 3186 1346 3190 3189 1117
1341	1508	3173	1379 3193 3192 1385 1120 1121 1119 3189 1117
1339	1508	3855	1338 1337 1481 3197 3194 3193 3192 1385 1120 1121 1119 3189 1117
1122	1508	3783	3196 3191 3568 1124 1126 2973 2974 2975 1129
1306	1508	3280	3185 3186 1345 3188 3187 1346 3190 3189 1117
1130	1508	2118	1126 2973 2974 2975 1129
253	1520	4379	2848 254 2857 2858 2891 54 2902
144	1520	2796	3546 145 2888 3543 3544
261	1520	2755	2859 2858 2891 54 2902
251	1520	2418	256 1354 94 2898
24	1520	2216	2885 146 2890 22 2898
929	1533	4159	940 3245 3246 3529 941 3257 3249 944 3258 945 3269 3389
1056	1533	3034	1057 3231 3242 1058 1059 3248 743
937	1533	2438	3232 3242 1058 1059 3248 743

APPENDIX – D

DETAILS OF PATH FOR FEEDER ROUTES

Origin stop	MRTS station	Length (meters)	Intermediate stops
88	5001	11170	2665 2666 2667 84 2664 3595 2774 82 83 81 79 2779 80 2778 2777
1429	5001	9814	192 2769 195 2770 196 2771 2866 197 3599 198 2853 2852 2851
194	5001	9767	135 3597 136 3596 358 138 2876 139 2867 2853 2852 2851
328	5001	10542	327 276 326 274 2656 2654 275 2658 2783 2779 80 2778 2777
87	5001	10887	3617 85 2668 2667 84 2664 3595 2774 82 83 81 79 2779 80 2778 2777
86	5001	11468	2674 2672 2673 85 2668 2667 84 2664 3595 2774 82 83 81 79 2779 80 2778 2777
134	5001	9302	135 3597 136 3596 358 138 2876 139 2867 2853 2852 2851
133	5001	7080	2770 196 2771 2866 197 3599 198 2853 2852 2851
374	5001	4324	197 3599 198 2853 2852 2851
272	5004	6911	2795 74 75 2794 76 3610 2784 2782 2781 269 2787 2788
25	5004	5507	2889 1477 2888 2885 2886 378 2887 1354 256 251 2856 252 2850
23	5004	6394	2883 2863 377 376 375 2854 2855 255 252 2850
144	5004	5537	3546 145 2888 2885 2886 378 2887 1354 256 251 2856 252 2850
273	5005	10898	2627 2626 2629 2630 2631 112 113 114 2798 5 73 2795 74 75 2794 76 77 2789 2785 2786 267 2846 2847
333	5005	10367	2628 273 2627 2626 2629 2630 2650 2649 3616 2651 76 77 2789 2785 2786 267 2846 2847
376	5005	4147	377 2863 355 2887 1354 256 251 2856 253 2849 263
270	5005	4074	2789 2785 2786 267 2846 2847
208	5006	10853	202 201 200 2875 142 2873 2505 2882 2883 23 2884 24 2885 146 2890 22 2898 21 2891 2858 2859 261 2844
1158	5006	9824	201 200 2875 142 2873 2505 2882 2883 23 2884 24 2885 146 2890 22 2898 21 2891 2858 2859 261 2844
3	5006	6693	2832 4 2800 72 1368 3577 2791 2839 334 6 2840 335
1425	5006	7377	2832 4 2800 72 1368 3577 2791 2839 2845 335 2860 265 264 262 258 257
2	5006	6102	3657 2831 67 3576 2835 3668 2919 2918 8 2958 7 2841 1449 2842
69	5006	5464	70 71 3577 2791 2839 334 6 2840 335
1109	5007	12188	1116 2978 2979 2980 2972 2971 963 2963 2960 2889 1477 2888 145 3546 144 2884 24 2885 146 2890 22 2898 21 2891 19 2916 20 2917 2843 260 2842
1157	5007	10205	2965 2878 2877 2872 1470 2502 357 25 2889 1477 2888 146 2890 22 2898 21 2891 19 2916 20 2917 2843 260 2842
110	5007	9757	2624 2625 111 112 113 114 2798 5 73 2795 272 271 2790 2791 2839 334 6 2840 2841 1449 2842
1127	5007	11617	1128 2972 2971 963 2963 2960 2889 1477 2888 145 3546 144 2884 24 2885 146 2890 22 2898 21 2891 19 2916 20 2917 2843 260 2842
1108	5007	9349	2976 3566 3565 3567 2889 1477 2888 2885 2886 378 2887 356 22 2898 21 2891 19 2916 20 2917 2843 260 2842
30	5007	7181	359 2502 357 25 2889 1477 2888 146 2890 22 2898 21 2891 19 2916 20 2917 2843 260 2842
141	5007	8292	140 2505 2882 143 3546 145 2888 3543 3544 1520 2898 21 2891 19 2916 20 2917 2843 260 2842
31	5007	7707	29 2954 3567 2889 1477 2888 2885 2886 378 2887 356 22 2898 21 2891 19 2916 20 2917 2843 260 2842
40	5007	7784	2954 3567 2889 1477 2888 3543 3544 1520 2902 56 2892 2924 2899 55 2955 2893 1485
74	5007	5644	2795 272 271 2790 2791 2839 334 6 2840 2841 1449 2842
23	5007	6470	2884 24 2885 146 2890 22 2898 1520 2902 54 2891 19 2916 20 2917 2843

			260 2842
72	5007	4339	1368 3577 2791 2839 334 6 2840 2841 1449 2842
355	5007	4227	2887 356 22 2898 21 2891 19 2916 20 2917 2843 260 2842
322	5008	9446	3177 1060 2994 2993 1097 1096 1095 1094 1460 2999 1093 3550 360 2998 3001 1476 342 1371 49 2895 47 2896 45 16 15
1493	5008	9080	1098 2988 2992 1491 340 2987 491 3540 2995 34 3541 1156 42 666 43 1475 342 1371 49 2895 47 2896 45 16 15
339	5008	8749	1492 2992 1491 340 2987 491 3540 2995 34 3541 1156 42 666 43 1475 342 1371 49 2895 47 2896 45 16 15
27	5008	6652	28 3542 37 38 41 1156 42 666 43 1475 342 1371 49 2895 47 2896 45 16 15
299	5009	11092	444 3178 3539 3176 339 1492 2992 1491 340 2987 491 3540 2998 3001 1476 342 1371 46 2906 58 2907 14 2897 11 2920 13 2922 59
290	5009	10992	3178 3539 3176 339 1492 2992 1491 340 2987 491 3540 2998 3001 1476 342 1371 46 2906 58 2907 14 2897 11 2920 13 2922 59
1104	5009	9850	2986 3563 3564 39 2997 2961 31 29 2954 40 2953 2952 41 1156 42 666 43 1475 342 1371 46 2906 58 2907
1103	5009	8744	1104 2986 3563 3564 39 2997 32 2962 2953 2952 41 1156 42 666 43 1475 342 1371 46 2906 58 2907
33	5009	6558	27 28 35 36 2995 3540 2998 3001 1476 342 1371 46 2906 58 2907
245	5009	6318	3575 2828 1356 300 381 379 1349 2829 2909 64 61 62 2837 2836 2922 59
4	5009	5525	2832 1425 2830 2 1 1351 1350 2829 2909 64 1523 1352 2948 2838 60 59
3	5009	5374	2832 1425 2830 2 1 1351 1350 2829 2909 64 1523 1352 2948 2838 60 59
71	5009	4635	70 69 2831 67 3576 66 65 63 62 2837 2838 60 59
68	5009	4244	3657 2831 67 3576 66 65 63 62 2837 2838 60 59
382	5011	6034	2928 3579 383 1483 395 336 289 288 287 278 2910 279 280 2911 2912 2913
343	5011	5519	57 1483 395 336 289 288 287 278 2910 279 280 2911 2912 2913
1359	5011	11217	1270 3195 1115 1110 1107 1112 1106 1493 1098 2988 341 2987 340 1491 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
1131	5012	10976	3208 1228 1359 1258 1079 1408 1076 3180 1114 1113 1111 2989 1107 1112 1106 1493 1098 2988 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
1446	5012	10853	3207 3184 1408 1076 3180 1114 1113 1111 2989 1107 1112 1106 1493 1098 2988 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
1445	5012	11433	3207 1131 3208 1228 1359 1258 1079 1408 1076 3180 3182 1075 3183 18 44 3539 322 3177 307 132 3004 186 3002 3553 1089 1088 315
1118	5012	10276	3195 1115 1110 1107 1112 1106 1493 1098 1101 2985 341 2987 340 1491 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
1073	5012	8863	1070 3183 18 44 3539 3176 339 1492 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
290	5012	8463	3178 3539 3176 339 1492 2992 1097 1096 1095 1094 1460 2999 1092 3551 691 1091 1090 362 1089 1088 315
1102	5012	8449	1103 1104 2986 3563 3564 33 27 28 3542 37 38 41 1156 42 666 43 1475 342 3000 320 319 317 316 1088 315
299	5012	8587	444 3178 3539 322 3177 1060 3005 3006 3004 186 3002 3553 1089 1088 315
1100	5012	8149	1493 1098 2988 2992 1491 340 2987 491 3540 2998 3001 1476 342 3000 320 319 317 316 1088 315
380	5012	7709	444 3178 3539 322 3177 307 132 3004 186 3002 3553 1089 1088 315
1099	5012	7940	339 1492 2992 1491 340 2987 491 3540 2998 3001 1476 342 3000 320 319 317 316 1088 315
475	5012	6201	3174 493 477 584 633 3007 3008 3009 1088 315
35	5012	6228	36 2995 3540 2998 360 3550 3649 1427 3551 691 1091 1090 362 1089 1088 315
724	5012	4250	1389 1499 3007 3008 3009 1088 315
1395	5013	4494	3160 732 3025 744 745 3013 3012 1383 1087 1488 3010 3026 370
718	5013	4447	724 728 3011 1081 1080 1347 1087 1488 3010 3026 370
756	5013	4405	3024 746 739 3018 3048 1078 3012 1383 1087 1488 3010 3026 370
1389	5013	4331	724 728 3011 1081 1080 1347 1087 1488 3010 3026 370
1411	5017	6421	654 3108 660 1390 1392 1419 3522 3037 3036 1489 3055 3035 1413 1453
655	5017	4069	656 3057 3525 1419 3522 3037 3036 1489 3055 3035
561	5018	10328	569 570 592 3103 3102 593 3101 2503 3099 544 3100 535 534 1437 529 531 3093 530 520 1418 3073 521 3066 517 3060 3062 3061 459
560	5018	8861	559 592 3103 3102 593 3101 554 553 1441 541 590 540 3106 539 3095 3067 518 1399 516 3060 3062 3061 459
597	5018	9248	596 594 558 3103 3102 593 3101 2503 3099 544 3100 535 534 1437 529 531 3093 530 520 1418 3073 521 3066 517 3060 3062 3061 459
1454	5018	8633	3102 593 3101 554 553 1441 552 543 3105 3106 539 3095 3067 518 1399 516

			3060 3062 3061 459
591	5018	8423	3103 3102 593 3101 2503 3099 544 3100 535 534 1437 529 531 3093 530 520 1418 3073 521 3066 517 3060 3062 3061 459
419	5018	7936	411 2821 418 415 417 416 2818 414 2819 1363 1364 3518 3516 538 3063 459
410	5018	8376	2823 2818 414 2819 1363 3514 3517 3518 3516 538 3063 459
1503	5018	6411	544 3100 535 534 1437 529 531 3093 530 520 1418 3073 521 3066 517 3060 3062 3061 459
1411	5018	6539	654 3108 660 1390 1392 1419 3056 657 2506 3059 3061 459
664	5018	5098	1390 1392 1419 3056 657 2506 3059 3061 459
1391	5018	4968	1390 1392 1419 3056 657 2506 3059 3061 459
406	5018	5664	408 405 1364 3518 3516 538 3063 459
655	5018	4375	656 3057 3056 657 2506 3059 3061 459
1400	5018	4532	3094 530 520 1418 3073 521 3066 517 3060 3062 3061 459
426	5019	6413	3519 3509 404 3510 3513 3515 432 456 450 3065 458
408	5019	5618	3516 3518 3517 3515 432 456 450 3065 458
409	5019	5568	404 3509 402 3508 403 3511 3512 446 3503 448 450 3065 458
582	5020	12179	3293 573 574 3498 575 577 588 576 579 545 578 3096 3077 513 3076 3074 549 3070 529 531 3093 530 520 528 1440 523 507 1434 3069 486 506 522 504
1524	5020	11155	573 574 3498 575 577 588 576 579 545 578 3096 3077 513 3076 3074 549 3070 3071 526 3072 1440 523 507 1434 3069 486 506 522 504
586	5020	10257	568 3276 3275 589 3097 1215 3096 3077 502 3078 505 3079 3075 487 3080 510 508 509 524 3069 486 506 522 504
566	5020	10068	567 3275 589 3097 1215 3096 3077 500 514 3098 1527 3074 3076 3080 510 508 509 524 3069 486 506 522 504
564	5020	10372	449 568 3276 3275 589 3097 1215 3096 3077 513 3076 3074 549 3070 3071 526 3072 1440 523 507 1434 3069 486 506 522 504
565	5020	9377	3277 589 3097 1215 3096 3077 502 503 3085 501 3075 483 1525 3069 486 506 522 504
556	5020	5647	550 546 3098 514 500 3077 502 503 3085 501 3075 487 3080 510 508 509 524 3069 486 506 522 504
498	5020	5334	3086 497 3087 533 488 3092 3081 595 482 483 1525 3069 486 506 522 504
499	5020	4643	3078 502 503 3085 501 3075 487 3080 510 508 509 524 3069 486 506 522 504
420	5021	9936	2817 421 424 425 2820 427 1439 3654 400 399 511 512 460 3506 453
551	5021	6895	3091 495 494 473 472 471 463 480 3505 462 461 1526 1502 460 3506 453
422	5021	6555	426 3519 3509 404 3510 3513 445 3512 446 3503 448 433 1365 447 453
496	5021	6096	3090 3086 497 3087 3088 3089 478 480 3505 3504 438 3500 1526 1502 460 3506 453
464	5021	5249	470 3502 467 634 3504 438 3500 1526 1502 460 3506 453
469	5021	5813	442 468 3501 394 440 1471 398 436 511 512 460 3506 453
441	5021	5457	468 3501 394 440 1471 398 436 511 512 460 3506 453
396	5021	4372	437 440 1471 398 436 511 512 460 3506 453
397	5021	5297	399 400 3654 401 428 429 431 452 3506 453
439	5021	4666	396 437 440 1471 398 436 511 512 460 3506 453
295	5022	9624	2617 292 291 1369 2807 2806 2509 249 2805 247 2827 228 241 2826 240 239 244 243 2937 1484 1405 2939 387 231
294	5022	10529	293 292 291 1369 2807 2806 2509 249 2805 247 2827 228 241 2826 240 239 244 243 2937 1484 386 2931 388 2932 231
1	5022	5469	1351 1350 2829 1349 379 381 300 1356 2828 1484 1405 2939 387 231
337	5022	4681	289 336 395 1483 383 3579 384 385 2930 2931 386 1484 1405 2939 387 231
298	5023	6753	297 310 2940 312 229 1450 2942 304 302 303
248	5023	6449	2814 2824 309 308 310 2940 312 229 1450 2942 304 302 303
242	5023	5079	2824 309 308 310 2940 312 229 1450 2942 304 302 303
407	5023	4874	310 2940 312 229 1450 2942 304 302 303
393	5023	4117	311 308 310 2940 312 229 1450 2942 304 302 303
57	5024	4637	343 2927 391 344 390 457 1452 180 3655 181 183 2945 3580 3672 225
569	5027	9896	570 592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 1467 1436
557	5027	11273	1454 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 639 640 3150 1391 1390 1392 1419 3522 3037 3523 3039 3524 5026 3673 1362 1436
597	5027	9182	596 594 558 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 1467 1436
559	5027	9419	592 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 671 669 668 667 3149 665 1457 3527 1436
1455	5027	10923	3274 591 3103 3102 593 3101 554 553 1441 541 542 3107 1410 1412 3109 639 640 3150 1391 1390 1392 1419 3522 3037 3523 3039 3524 5026 3673 1362 1436
555	5027	10292	2503 3101 554 553 1441 541 542 3107 1410 1412 3109 681 642 643 684 3130

			685 3267 3264 3266 674 3111 1497 3123 1496 3122 667 1467 1436
1478	5027	4473	651 690 3119 644 3129 683 1479 681 3109 639 640 3150 1391 1390 664 661 3148 663 3527 1436
652	5027	5325	3110 3107 1410 1412 3109 671 669 668 667 1467 1436
680	5027	3913	3130 685 3267 3264 3266 674 3111 1497 3123 1496 3122 667 1467 1436
558	5028	9025	3103 3102 593 3101 554 553 1441 541 542 3107 3110 1411 654 3108 660 1390 664 661 3148 663 3527 1457 665 3149 667 3122
550	5028	8300	556 547 3100 544 1503 543 552 1441 541 542 3107 1410 1412 3109 681 687 686 3265 3114 3266 674 3111 3112 675 1498 3124 3123 1496 3122
745	5028	4876	3013 3018 3017 1348 3020 3022 759 3049 857 850 858 3132 1072 3120 3121 3122
1382	5028	4376	3016 3019 1398 3021 1426 3135 1480 3050 3051 1074 3675 1468 3133 1071 3121 3122
290	5029	10922	3178 444 380 475 3174 493 477 584 633 3007 1499 1389 724 718 1395 3160 3164 859 2508 3548 1535 3549 835 3158 3159 1038 3152 3136 1393 726 3155 1372 723 3671
299	5029	10512	444 380 475 3174 493 477 584 633 3007 1499 1389 724 718 1395 3160 3164 859 2508 3548 1535 3549 835 3158 3159 1038 3152 3136 1393 726 3155 1372 723 3671
1540	5029	8649	3339 1442 3661 3344 698 953 3343 1423 697 696 3260 624 854 852 1541 3263 851 679 678 645 3118 3117 3116 3146 3147 3144 3139 729
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1539	5029	9063	1540 3339 1442 3661 3344 698 953 3343 1423 697 696 3260 624 854 852 1541 3263 851 679 678 645 3118 3117 3116 3146 3147 3144 3139 729
637	5029	8767	636 3175 3602 3161 3160 732 3025 746 3024 717 758 759 3049 857 850 858 3132 1072 3120 3128 3127 3126 1494 1420 1474 3171 733
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744	5029	5707	3025 746 3024 756 3548 1535 3549 835 3158 3159 1038 3152 3136 1393 726 3155 1372 723 3671
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1394	5029	5242	3537 3259 3256 3254 933 3253 3528 3147 3144 3139 729
689	5029	6251	3162 3163 3164 859 2508 3548 1535 3549 835 3158 3159 1037 902 965 3151 1404 3555 932 3157 3155 1372 723 3671 5029
816	5030	9923	1027 3394 1307 1316 1028 719 1025 3223 1388 3224 907 909 3225 908 911 3228 3227 918 917 3234 3235 3532 1376 3173
834	5030	11542	967 837 836 3433 1407 838 3441 1049 880 3384 1431 775 3591 3385 1409 3383 1505 3351 743 1533 3389 3269 947 943 946 3247 3244 939 3236 3533 740 3241 3239 3531 3238 1438 3173
823	5030	11138	840 841 3386 3426 1458 3376 1040 827 3374 1495 3381 1039 3373 1044 1043 1035 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
769	5030	11497	770 777 3661 1442 1461 3342 1361 3345 849 848 1514 1357 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
1328	5030	11786	3217 1322 199 3538 3222 906 1387 3224 903 1465 3534 924 901 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
821	5030	12072	3589 841 3386 1041 3375 1042 3380 3382 1537 3586 1374 1462 1538 1046 1443 3384 1431 775 3591 3385 1409 3383 1505 3351 743 1533 3389 3269 947 943 946 3247 3244 939 3236 3533 740 3241 3239 3531 3238 1438 3173
818	5030	10191	846 3376 1040 827 3374 1495 3381 1039 3373 1374 1045 1054 3360 3356 3361 1056 1057 3231 3242 3243 741 3236 3533 738 3237 737 1430 925 3530 736 3138
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964	5030	10601	961 960 3442 957 3354 955 956 954 3345 849 848 1514 1357 3384 1431 775 3591 3385 1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
1504	5030	8709	3347 1459 3342 3344 698 953 3343 1423 697 696 3260 624 854 852 1541 3263 851 679 678 645 3118 3117 3116 3146 3147 3144 3145 927 925 3530 736 3138
1309	5030	8364	3391 1025 3223 1388 3224 907 909 3225 935 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
805	5030	8155	806 3372 1030 808 3371 898 923 3364 3363 922 921 920 919 3228 3227 918

			917 3234 3235 3532 1376 3173
477	5030	8321	584 633 3007 1499 1389 724 718 1395 3160 3164 859 2508 3548 1535 3549 835 3158 3159 1038 3152 3136 914 3172 1376 3173
847	5030	9485	3367 3368 3369 805 806 3372 809 3534 1465 903 3224 907 909 3225 908 911 910 3226 3227 918 917 3234 3235 3532 1376 3173
1308	5030	8033	3221 3223 1388 3224 907 909 3225 935 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
1036	5030 .	8766	3374 1495 3381 1039 3373 1044 1043 1035 898 923 3364 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
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1310	5030	8987	3221 3223 1388 3224 903 1465 3534 3670 3363 922 921 920 919 3228 3227 918 917 3234 3235 3532 1376 3173
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1415	5030	5087	1409 3383 1505 3351 743 3248 742 3243 741 3236 3533 740 3241 3239 3531 3238 1438 3173
945	5030	5271	3269 3389 1533 743 3248 1059 1058 3242 3232 937 3233 3241 3239 3531 3238 1438 3173
944	5030	4135	3249 3257 941 3529 3246 3245 3237 737 1430 925 3530 736 3138